

**THE DEVELOPMENT OF A MODEL FOR  
ORGANISATIONAL INTEGRATION  
THROUGH  
INTEGRATED HYPOTHESIS  
DEVELOPMENT**

A thesis submitted for the  
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1991**

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To Robert

*Education makes us what we are*

Claude-Adrien Helvétius (1715-71)

## ABSTRACT

The history of modern manufacturing organisations is relatively short. It owes its beginnings to men like *Eli Whitney* and *Henry Ford*, individuals whose life experiences consisted of interwoven engineering theory and practice. Men such as these designed and built *integrated* organisations.

Throughout the twentieth century these integrated organisations have been on the decline, as individuals with broad technical and practical backgrounds become less common. As a result, manufacturing organisations have been forced to rely on the interaction of *experts* in the development of their new products.

The problem of integration affects organisations in two distinct ways, firstly there is the integration of organisational functions for the effective operation of the firm as a system. While the integration of beliefs necessary, within an individual, for the production of valid design hypotheses, represents the second area of concern.

The need to divide a firms activities into a number of *specialist* areas, is the cause of organisational integration problems. To understand the relationship between functional groups and to assess the causes of organisational dis-integration, Stafford Beer's *Viable System Model* is used.

It is stated that the fundamental cause of dis-integration, in the development of valid design hypotheses, is the decline of the *integrated individual*. Where in the past an engineer could empathise with an accountant or machinist, from his own experiences, today's *specialists* cannot. Gone is the integrating system of beliefs, once developed through years of on the job training within the many areas and levels of the organisation.

The *Purposeful Design Model* provides an architecture of the necessary roles to be performed, to ensure a designer can develop the integrated system of beliefs, necessary for the truly integrated development of design hypotheses. An extension of the model shows how its general use as a hypothesis development model, can help bring about overall organisational integration.

The model is used to place existing design methods into a wider framework, and to assess their integrative abilities. To further elucidate the power of the *Purposeful Design Model* a number of case studies are considered.



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# CONTENTS

## ABSTRACT

## ACKNOWLEDGEMENTS

## LIST OF FIGURES

<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
1.1	Background and Literature	1
1.1.1	Integrated Manufacturing	2
1.1.2	The Decline of the Integrated Individual	3
1.1.3	An Attempt at Re-Integration	5
1.1.4	Design as the Integrating Medium	10
1.1.5	Computer Integrated Manufacturing	14
1.1.6	Organisational Design	16
1.2	Aim and Scope of Present Work	18
<b>2</b>	<b>CONCEPTS AND DEFINITIONS</b>	<b>20</b>
2.1	Introduction	20
2.2	Operational Defining	20
2.3	Ackoff's Operational Defining Procedure	21
2.4	Operational Definitions	22
2.4.1	Integration	22
	(a) Historical Definition of Integration	22
	(b) Modern Definitions of Integration	23
	(c) Essential Properties of Integration	24
2.4.2	Coordination	24
	(a) Historical Definition of Coordination	24
	(b) Modern Definitions of Coordination	25
	(c) Essential Properties of Coordination	26
2.4.3	Designing	27
	(a) Designing Defined	27
	(b) Essential Properties of Designing	28
	(c) Designing - Integration or Coordination?	29
2.4.4	Planning	29
	(a) Planning Defined	29
	(b) Essential Properties of Planning	30
	(c) Planning - Integration or Coordination?	31
2.5	Design	33

<b>3</b>	<b>INTEGRATED MODELS</b>	<b>39</b>
3.1	Introduction	39
3.2	The Viable System Model	39
3.3	The Purposeful System	49
3.3.1	Beliefs and Feelings	51
3.4	Integrated Systems	55
<b>4</b>	<b>THE PURPOSEFUL DESIGN MODEL</b>	<b>59</b>
4.1	Introduction	59
4.2	Background	60
4.3	Interaction Models	61
4.3.1	The Designer-Client Interaction	61
4.3.2	The Designer-Co-Designer Interaction	64
4.3.3	The Designer-Functional Expert Interaction	67
4.3.4	The Designer-Belief Expander Interaction	69
4.3.5	The Designer-Critic Interaction	71
4.3.6	The Designer-Sub-Designer Interaction	74
4.3.7	The Designer-Design Hypothesis Freezer Interaction	80
4.3.8	The Designer-Documentor Interaction	82
4.3.9	The Designer-Administrator Interaction	85
4.3.10	The Team Member-Developer Interaction	88
4.4	Role Relationships	90
<b>5</b>	<b>THE PDM IN A WIDER CONTEXT</b>	<b>92</b>
5.1	Introduction	92
5.2	Existing Design Methods in the Larger Framework of the PDM	92
5.2.1	Systematic Design Methods	92
5.2.2	Design Fors	97
5.2.3	Design by Features	98
5.2.4	Integrated Product Development	99
5.2.5	The Concept of Dispositions	100
5.3	Parallel Design Teams and Integrated Planning	100
5.4	A Control System for the PDM	102
5.4.1	Designer-Client Interaction	104
5.4.2	Critic-Critic Interaction	104
5.4.3	Designer-Critic Interaction	107

5.4.4	Designer-Co-Designer Interaction	109
5.4.5	Designer-Functional Expert Interaction	111
5.4.6	Designer-Belief Expander Interaction	111
5.4.7	Designer-Sub-Designer Interaction	111
5.4.8	Designer-Design Hypothesis Freezer Interaction	113
5.4.9	Designer-Documentor Interaction	115
5.4.10	Designer-Administrator Interaction	115
5.4.11	Team Member-Developer Interaction	117
5.5	A Computer Driven Purposeful Design Model	117
<b>6</b>	<b>CASE STUDY ONE: THE COLLAPSE OF ROLLS-ROYCE</b>	<b>120</b>
6.1	Introduction	120
6.2	Short History of Rolls-Royce	120
6.3	Product Development	121
6.3.1	RB211 Contract and Development	122
6.3.2	Violations of the Purposeful Design Model	127
6.4	Summary and Conclusions	131
<b>7</b>	<b>CASE STUDY TWO: THE FLIXBOROUGH DISASTER</b>	<b>132</b>
7.1	Introduction	132
7.2	Events leading up to June 1	132
7.3	Conclusions of The Court of Inquiry	135
7.4	Analysis of Decision Process	137
7.5	Summary and Conclusions	139
<b>8</b>	<b>NEW ZEALAND RAILWAYS: A PRODUCT DEVELOPMENT EXAMPLE</b>	<b>140</b>
8.1	Introduction	140
8.2	Sociological Research Methods	141
8.3	New Zealand Railways: 1863-1990	143
8.4	Railways Pre 1970's	150
8.5	Railways Mid to Late 80's	153
8.6	Railways in the 1990's	159
<b>9</b>	<b>DESIGN AND DEVELOPMENT OF THE GST CONTAINER</b>	<b>173</b>
9.1	Introduction	173
9.2	A Purposeful Description of the GST Container Project	175
9.2.1	Recursion 0 - Conceptual Design	176

(a)	Designer-Client Interaction	177
(b)	Designer-Co-Designer Interaction	178
(c)	Designer-Functional Expert Interaction	179
(d)	Designer-Belief Expander Interaction	182
(e)	Designer-Critic Interaction	182
(f)	Designer-Sub-Designer Interaction	184
(g)	Designer-Design Hypothesis Freezer	184
(h)	Designer-Documentor Interaction	185
(i)	Designer-Administrator Interaction	185
9.2.2	Recursion 1 - Embodiment Design	186
(a)	Designer-Client Interaction	187
(b)	Designer-Co-Designer Interaction	188
(c)	Designer-Functional Expert Interaction	188
(d)	Designer-Belief Expander Interaction	189
(e)	Designer-Critic Interaction	192
(f)	Designer-Sub-Designer Interaction	194
(g)	Designer-Design Hypothesis Freezer	195
(h)	Designer-Documentor Interaction	195
(i)	Designer-Administrator Interaction	195
9.2.3	Recursion 2 - Detailed Design	196
(a)	Designer-Client Interaction	196
(b)	Designer-Co-Designer Interaction	196
(c)	Designer-Functional Expert Interaction	197
(d)	Designer-Belief Expander Interaction	197
(e)	Designer-Critic Interaction	199
(f)	Designer-Sub-Designer Interaction	202
(g)	Designer-Design Hypothesis Freezer	202
(h)	Designer-Documentor Interaction	202
(i)	Designer-Administrator Interaction	203
9.3	Summary of the GST Project	203
10	CONCLUSIONS	205
	REFERENCES	207

<b>APPENDIX A</b>	<b>STAFFORD BEER'S VIABLE SYSTEM MODEL: NON-TECHNICAL VERSION.</b>	<b>235</b>
<b>APPENDIX B</b>	<b>CHARACTERISTICS OF PEOPLE</b>	<b>266</b>
<b>APPENDIX C</b>	<b>GST CONTAINER</b>	<b>255</b>

## LIST OF FIGURES

### FIGURE

1.1	Integrated Conceptual Spares	6
1.2	An Example of the Brisch Classification System	7
1.3	An Example of a Producibility Tip Sheet	8
1.4	Examples of Producibility Tips	8
1.5	The Computer-Integrated Manufacturing System	15
2.1	Relationship between the Designer and Others	34
2.2	Product Design Activity Model	36
2.3	Elements of the Product Design Specification	37
3.1	Attenuation and Amplification of Variety from Environment to System and vice versa	41
3.2	Interacting Operational Elements	42
3.3	Relationship between Operational Elements and the Meta-System	43
3.4	The Emerging Model	44
3.5	Operational Elements, Meta-System and Communication Channels	45
3.6	The Viable System Model	48
3.7	Diagrammatic Representation of the Purposeful System Model	50
3.8	Beliefs, Feelings and the Purposeful System Model	54
3.9	The Purposeful Design Model as used in this Thesis	54
4.1	Designer-Client Interaction	62
4.2	Feelings Mechanism	63
4.3	Designer-Co-Designer Interaction	66
4.4	Designer-Functional Expert Interaction	68
4.5	Designer-Belief Expander Interaction	70
4.6	Designer-Critic Interaction	72
4.7	The Recursive Nature of Design	75
4.8	Designer-Sub-Designer Interaction	78
4.9	Designer-Design Hypothesis Freezer Interaction	81
4.10	Designer-Documentor Interaction	84

4.11	Design-Administrator Interaction	87
4.12	Team Member-Developer Interaction	89
4.13	Role Relationships	90
5.1	General Approach to Design	93
5.2	Organisational Integration through Integrated Hypothesis Development	101
5.3	A System of Interacting Critics	105
5.4	Control System for Critic-Critic Interaction	106
5.5	Control System for Design-Critic Interaction	108
5.6	Control System for Designer-Co-Designer Interaction	110
5.7	Control System for Designer-Sub-Designer Interaction	112
5.8	Control System for Designer-Design Hypothesis Freezer Interaction	114
5.9	Control System Designer-Administrator Interaction	116
6.1	Recursive 0 - Rolls-Royce	122
6.2	Recursive 1 - Engine Production	123
7.1	20 Inch Dog-Legged Connecting Section	134
8.1	Recursion 0 - New Zealand Railways	151
8.2	Recursion 1 - Rail Services	152
8.3	Recursion 0 - New Zealand Railways, Mid to Late 1980's	155
8.4	Recursion 1 - Rail	156
8.5	Recursion 2 - Rail Freight Markets	158
8.6	New Zealand Railways Press Release	160
8.7	Recursion 0 - New Zealand Rail	163
8.8	Recursion 1 - Transport	164
8.9	Recursion 2 - Rail Transport	165
8.10	Recursion 3 - Rail Freight Systems	166
8.11	Recursion 3 - Expanded Detail	167
8.12	Recursion 4 - A Market Segment	168
8.13	An Alternative Management Structure	170
9.1	The GST Container	173
9.2	Recursive Levels of the GST Project	175
9.3	Existing Container Design	177



9.4	Door Securing Mechanism	180
9.5	The Construction of the GST Container Ends	191
9.6	The Corrugated Construction of Conventional Container Ends	191
9.7	GST Container Floor Design	193
9.8	GST Container Structural Arrangement	194
9.9	GST Curtain Before Modification	200
9.10	Curtain After Modification	200
9.11	Modification to Allow Curtain Replacement	201

# CHAPTER 1

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## INTRODUCTION

### 1.1 Background and Literature

Product development is one of the the process through which manufacturing organisations attempt to remain commercially viable. It is the synthesis of a diverse set of functional activities, and if done well will guarantee success in the market place, done badly and it dooms the enterprise to extinction.

Manufacturing comprises the technical and economic processes that convert raw materials, and energy into end products [1], it includes all activities, from the perception of a need, through the conception, design and development, production, marketing and ultimately support of the product in use [2].

While man has been producing artifacts for thousands of years, mass manufacturing as we know it today has a relatively short history. It was man's inability to measure to a high degree of accuracy that delayed mass manufacture until the middle of the 19th century. An American, Eli Whitney, applied industrial measurement techniques for the first time in the 1830's, in his firearms factory, thus allowing him the opportunity for mass production.

It was Whitney's use of hand-made master gauges, for every critical dimension, that made such mass production possible [3]. The use of gauges guaranteed interchangeability between components, meaning that then traditional method of shaping each component, to ensure its fit, was deemed obsolete. This not only meant that productivity could be increased but it also opened the way for mechanisation.

### 1.1.1 Integrated Manufacturing

As machines were produced to manufacture specific components a need arose for better industrial organisation within factories. Plant layout now became planned as machines and processes were sequenced, enabling work pieces to flow more easily from one station to the next. Product and process were designed together, dedicated machinery became the norm, with often the same designer being responsible for the design of both. It was Henry Ford who in the early 20th century fully embraced the concept the concurrent design of product and process in the manufacture of his now famous Model T.

Ford's design philosophy was simple, build one basic design year after year and allow only a few optional add-ons. The supporting manufacturing strategy was to design and build specialised production machines capable of great efficiency [4]. Pivotal to Ford's success was his use of a relatively small group of highly skilled individuals,<sup>1</sup> who worked closely together to develop; the product, processes, fixtures, gauges, factory layout, purchasing systems, and quality systems. By using a small and very skilled team, while keeping to a philosophy of design simplicity, Ford achieved an integrated approach to product development. Ford's only mistake was that he failed to include the activity of marketing into his development *team*, as a result he failed to see the threat that his rival General Motors posed.

G.M. had seen the potential for exploiting a number of different markets and designed vehicles for a variety of price ranges. Its production system was designed to be flexible, capable of producing parts for a number of cars. Ford's low priced Model T began to lose its appeal to the more expensive Chevrolets built by G.M., and in 1926, while Ford struggled to introduce the Model T's successor, it lost its market lead to G.M., a lead it has never regained [1].

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<sup>1</sup> Ford's designers were his best mechanics and experienced *practical* men from various industries [4].

While Ford was busy building his empire in the United States, Henry Royce was at work establishing himself as the master of British automotive engineering. As with Ford, Royce was a very practical man, a man whose life experiences enabled him to achieve what he did.

After working for a year as an apprentice with the *Great Northern Railway*, Royce was employed in a number of jobs, including working for a company of tool makers and the *Electric Light and Power Company* in London, all the while endeavouring to improve his education by attending lectures and polytechnic classes. In any spare time, he had left available to him, he would be found in his landlord's shed, which contained a lathe, vice and a number of tools [5]. Ford and Royce, along with numerous other designers of the time e.g. Whittle, Ricardo and Hooker to name but a few, were designers with a well integrated<sup>2</sup> background of practice and theory.

### 1.1.2 The Decline of the Integrated Individual

In the early half of the 20th Century the method of apprenticing was very common in becoming a qualified engineer. In this system apprentices would spend a number of years working on the *shop-floor* developing tradesman skills, while attending lectures in the evenings or during release from employment. As a result of this the individuals involved *knew* what could and could not be done in practice. If the young designer was ever unsure about some practical detail, his contacts on the shop floor would provide him with the necessary information. As the century progressed, however, and the demand for technically qualified people changed e.g. WW1 and WW2, along with changes in society, the method of apprenticing became less and less common, and thus the vital integrating links were lost to the shop floor.

As R.S. Medlock stated in a paper to the Institution of Mechanical Engineers [6] when discussing design changes made at the shop floor level to improve the production of castings .

---

<sup>2</sup> Integration is defined in Chapter 2.

*The alert graduate (working as an apprentice on the shop floor) notices such things and one day he may be in a position to improve the feedback of information. Who knows what savings in both production costs and overheads he may make?*

In the same vain K.R. Evans [7] while talking about training young apprentice engineers, by placing them in such departments as manufacturing, finance, sales, design office, drawing office, and where appropriate the construction site.

*Such a man will then be employed either in manufacturing, design or sales, with a background which will enable him to talk on understanding terms with his fellow-employees at all levels and, at the same time, to co-operate intelligently with his fellows in associated departments with an understanding of their problems.*

Benefits of the apprenticing systems were not seen as being short term in nature, but rather something for the future, again quoting Medlock [6].

*Head of departments should be encouraged to lend their active support, take a broad view of the long-term aims of the firm's training schemes, and to make allowances for any temporary inadequacy of the graduate. For example, the potential designer may not show brilliance during his brief period in the estimating office, and may seem to take much valuable time in being taught his job, but he will have a better appreciation of economic design when he reaches his ultimate position if he has had some experience of the other mans job.*

Even as early as the 1950's engineering societies were recognising the deterioration in the wide base of knowledge possessed by Mechanical Engineers. Professor J.A. Pope stated in 1954 [8]:

*It is obvious that the engineering graduate leaving the university today is much less of an engineer than his counterpart was in 1910.*

It was felt by Pope, that the cause of this lay in the fact that engineering students were receiving an ever increasing scientific content in their training, this being at the expense of workshop practice, machine drawing and design. He went as far as to say that universities do not produce engineers, but rather engineering scientists.

After only 100 years of mechanical manufacturing, the type of individuals who had been so essential in the founding of the industry were starting to disappear, as the route to becoming a professional mechanical engineer moved away from a carefully structured apprenticing type system to a largely academic pursuit.

As this trend continued the manufacture of artefacts become seen as a serial set of activities, each being performed by a specific specialist individual. Now the mental process to produce a fully integrated product<sup>3</sup> was not contained in the mind of a single individual, but rather distributed amongst a diverse group whose life experiences were quite different. As a result of this designs failed to incorporate other than functional design considerations; manufacturability, maintenance and cost failed to be considered adequately: designers were no longer integrated. The result of this was long lead times, poor quality, and lost opportunities as products arrived late to the market.

### 1.1.3 An Attempt at Re-Integration

The obvious solution to this problem would appear to lie in getting functional representatives to communicate during the design process, however, as Stafford Beer [9] indicates, verbal communication does not ensure requisite variety<sup>4</sup>, meaning that discussions alone will not solve the problem. Britton and Whybrew [10] discuss the issue of functional specialisation, and the apparently obvious solution of improved communication, as the *Fallacy of Functional Specialisation* stating the fallacy as:

*The design and manufacture of something is performed in a sequence of stages each stage being performed by a specialist. Therefore the problem of integration is to get these specialists to work together; specifically to get them to communicate with each other more effectively.*

Thus the real integration problem is not one of communication, but rather the mapping of one individuals experiences on to those of another, Britton and Whybrew call this a mapping of *Conceptual*

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<sup>3</sup> One that incorporates all the essential characteristics to produce a product for the market i.e. the requirements of manufacturing, marketing, finance, quality control etc.

<sup>4</sup> The law of *Requisite Variety* states that *only variety can destroy variety*.

*Spaces*, this is shown below for the case of a designer and a process planner.

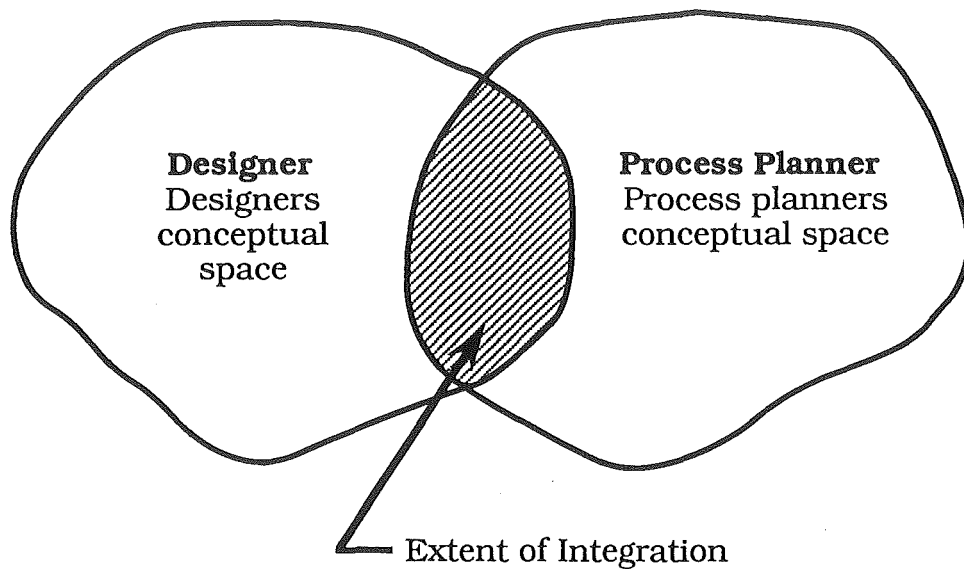


Figure 1.1 Integrated Conceptual Spaces

The difficulty that is then faced is how to map one conceptual space to another.

Over the past few decades attempts have been made at achieving such a mapping, although the actual concept of mapping is relatively recent. Group Technology (GT) [11] is by far the most successful attempt to date. It is a system which requires an entire organisation, from top to bottom, to accept a common planning focus, and thus achieves its success by forcing an integrated approach at all organisational levels [13]. At the highest levels it is a concept that ties departmental planning together, while at the lowest levels, it uses production flow analysis to classify and code new parts, thus tying together the design of components and the production process. By classifying all new components via a classification plan, such as Brisch [see figure 1.2], or Opitz [12], the components *family*<sup>5</sup> can be determined, and thus the Group Technology cell needed to produce it identified.

<sup>5</sup> The word *family* is used as a name for any list of similar parts [11].

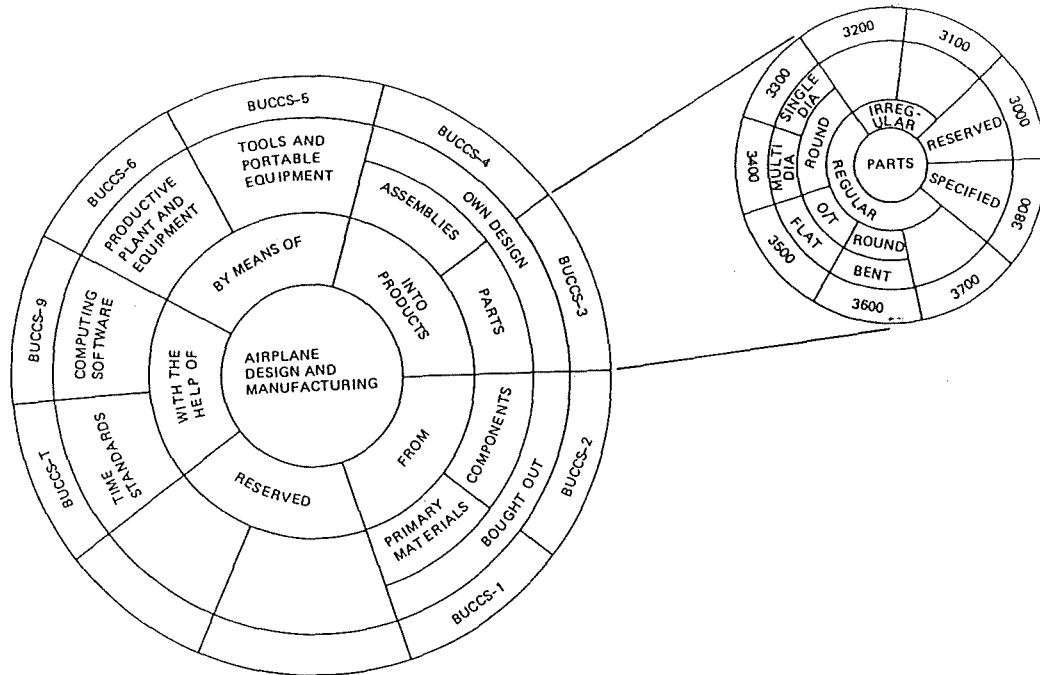


Figure 1.2 An example of the Brisch classification system [From 12]

While group technology is the most all encompassing method for trying to regain organisational integration, particularly in the areas of design and production, a number of other techniques have proved useful to a lesser extent.

While integral to the success of group technology, classification and coding can, and has been, used successfully on its own, however, the potential for design/production integration is far more limited. Group technology is essentially an integrating philosophy, while classification and coding is one of the tools used in achieving that integration. Without the definite links established through G.T., classification and coding achieves only limited success, through design simplification and easy retrieval of previously designed components, as well as the process plans for those components. However, every new component entering the system still needs to have its process route determined by a process planner, without the assistance of knowing what *group* of machines it should be produced on. Classification and coding by



itself also only provides links at the lowest levels of activity, unlike G.T. it has no over riding philosophy that pulls planning together at the higher organisational levels.

The use of *producibility tips* is another link that has been developed to try and achieve a degree of design and production integration. Again it requires some sort of classification system, and works by tying information about the penalties associated with design decisions to particular product families [15]. Examples of such tips are shown in figures 1.3 and 1.4.

PRODUCIBILITY TIP - TIP NUMBER 199			
RECOMMENDATION - USE STANDARD STOCK DIAMETER NO CHAMFERS IF POSSIBLE			
BASIC COST = 100%	1.5 X COST	3.0 X COST	5.0 X COST
	 ± .001	 ± .0005	 ± .0001

Figure 1.3 An Example of Producibility Tip Sheet [After 15]

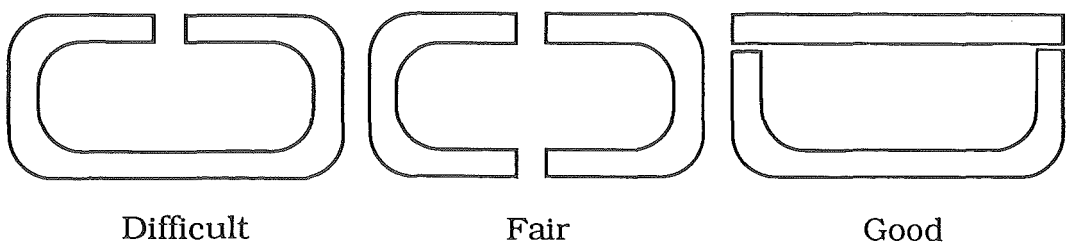


Figure 1.4 Examples of Producibility Tips [After 15]

Producibility tips aim at ensuring that the design decisions that are made, minimise such considerations as cost, by eliminating such things as over specification of tolerances and surface finishers, and ensuring maximum ease of manufacture.

By doing this, design and production are forced to work to a common set of assumptions about production factors. This therefore results in closer integration at the lower organisational levels, however, this again does little to aid organisational integration at the higher levels.

Over time most manufacturing organisations will be faced with an explosive proliferation of parts, this is generally the result of designers being permitted to design new components for each new product, rather than being required to search a database for a suitable previously designed part. The result being that firms, by necessity, must carry extensive inventories in order to satisfy production demands, as well as service products already sold. Additionally it means that a large number of similar components are designed, differing only in such detail as bolt hole sizes, for example.

Standardisation and simplification are employed to overcome this problem and at the same time help to integrate more closely design and production.

The American National Standards Institute (ANSI) defines standardisation as:

*Standardisation is a tool for securing optimum utilisation of resources and maximum efficiency of operations through formed establishment of the most suitable predetermined solutions to re-occurring problems and needs. [From 14]*

while simplification was defined as:

*Simplification is a management tool consisting of positive actions to reduce the variety of any data to its least common number, commensurate with the demands of the organisation.*

Standardisation is intended to bring all organisational activities into line, by using a common set of assumption on which to base their activities, while simplification is a process by which to reduce the variety to be standardised.

The likely benefits of simplification and subsequent standardisation include such things as:

- Fewer drill sizes required
- Fewer tapered reamers required
- Fewer after-market parts to stock
- Fewer annual purchases
- Reduced inventories/investment, etc [14].

Thus simplification by reducing the level of variety reduces the complexity of the integration issue, but does little or nothing to solve it. Through standardisation a common set of objectives can be determined that will help to bring conceptual spaces together, however, as time passes and technologies change, the degree of integration is likely to diminish.

Burbidge et al [16,17] also see integration resulting from simplification, however, as stated previously it does little to solve the problem, it simply reduces the complexity of the integration issue for some small epoch of time. In the long run it does nothing to ensure that functionally diverse conceptual spaces are mapped on to one another.

#### **1.1.4 Design as the Integrating Medium**

In recent years the push to improve integration of functional activities, has focused on the design process, and the extent to which decisions made at this stage of product development affects every aspect of the products production, operation, maintenance and eventually disposal. Thus considerable work has gone into methods of *Design Fors*, such as *Design for Producibility* or *Manufacturability* [18,19,20] and *Design for Assembly* [21,22], not to mention numerous other *Design Fors*.

The basis of this work has been the development of a series of procedures to aid the designer in making decisions about such things as the ease of manufacture or assembly. In this way *Design Fors* are simply an extension of the *Producibility Tips* discussed previously.

The difficulty that a designer may be faced with, using such a system, is that if he is required to incorporate Design for Cost, Design for Manufacturability and Design for Assembly considerations, for example, he may not be able to resolve conflicting issues within the scope of the various guidelines. The consequence of this is that he may select a course of action which is wholly inappropriate from a company wide perspective, and thus we are back to the integration problem once more.

Another limitation with the *Design For* philosophy is that it is intended for directing the design decisions at the lowest levels. The result of this, is that any degree of integration that may occur will only be at that level. It does not provide any solution to the more challenging integration problems at the departmental planning level.

The aim of *Design Fors* is to make life cycle issues apparent to the designer at a time when he is deciding the structure and form of the artifact. As Andreassen and Olesen [23] put it, design is the *agent* while the departments effected by its decisions are the *victims*; victims of good decisions, and victims of bad decisions. Design Fors tend to be rather specific, and therefore fail to satisfy divergent objectives, the advent of Designing for the Life Cycle is an attempt to broaden the basis of decision making during the design process.

In designing for the Life Cycle, design issues are no longer seen in isolation, but rather as a interconnected set of considerations, encompassing the manufacture, operation, maintenance and eventual disposal of the artifact to be designed. While the individual issues are important in life cycle design, equally important is the parallel development of such things as; process design, marketing strategy and sales policy. By developing these

in parallel, valuable time is not lost through the continual redesign of the product to incorporate important considerations discovered missing at a late stage. Thus parallel development aims to ensure a cross flow of information into the design process, at a time when the designers decisions are being formulated.

The concept of design for the life cycle is not particularly new, for example Matousek [24] and Asimow [25], however in recent years it has received considerably more attention, under a variety of different names. Common titles for this approach include; *Simultaneous Engineering* [26], *Concurrent Engineering* [1], or *Integrated Product Development* [27]. While authors such as those indicated are active in investigating the complex interactions of product development, another group of researchers are busy looking at a portion of that process. Research into the design process, and the management of that process.

Although not new, it is something that has received considerable attention in recent times, as a result of the increasing competitive pressures faced by manufacturing firms, and the integral part that design plays in their survival. While a large body of researchers tackle the issue of what the design process is, or what process designers follow while designing, it appears that it is German researchers who are attempting to provide rigorous models of the design process and procedures for designers to follow, thus helping to ensure success in the design of new products.

As early as the 1960's the German researcher Dr. -ING Matousek [24] was proposing a systematic approach to the solving of design problems, in the 70's Gerhard Pahl and Wolfgang Beitz published their systematic guide to design<sup>6</sup>, which was seen as a synthesis of the wide body of German literature on the subject. In the early 80's Vladimir Hubka published his work on the systematic approach [29], he later developed a generalised version of this applicable to any technical system and titled it the *Theory of Technical Systems* [30]. As a guide for designers employed by industry, the German Standards Association, Verein Deutscher

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<sup>6</sup> Their book titled *Konstruktionslehre* was later translated in to English under the title *Engineering Design* [28] by Ken Wallace for the Design Council, London.

Ingenieure (VDI) published VDI 2221 [31] as a standard for the *Systematic Approach to the Design of Technical Systems and Products*. While referencing a wide body of literature, it appears to be based primarily on the work of Pahl and Beitz, although it is generalised to widen its applicability beyond purely mechanical engineering design.

As the systematic approach was developing and gaining acceptance in Germany, it was the systems approach which was establishing itself in Great Britain. According to Hales [32] the systems approach, while having its roots in engineering and the sciences, was re-introduced into British engineering through the management and organisational approach developed by Checkland [33]. As a result of the systems approach the design process and its role within an organisation began to be seen as being hierarchical, or multi-level. More recent papers relating purely to the design process describe it as a hierarchy [34], quasi-hierarchy [35] or as being recursive [36]. All of these indicating that design is essentially a process occurring at a number of different levels, each level having a different focus.

While a large body of design researchers have been concentrating on the theory associated with how designers design, a small but growing number have been analysing the process by observing designers at work. Two such studies have been those conducted by Hales [32] in Great Britain and LTM Stomph-Blessing [37] in Holland, Hales in his project acting as a participant observer. While this type of research is on the increase, it appears that the tools necessary to undertake it are still in need of development, as Stomph-Blessing [37] points out a number of methodological difficulties remain with this type of research.

While the actual design process has received considerable attention a number of researchers have been concentrating on the process of product development, a process in which design is seen as the integrating medium of all other functional activities [38]. Notable in this area are Andreassen [27,23] and Pugh [39], along with such bodies as The Institution of Production Engineers [20] and the British Standards Institution [40]. Each of these authors

and bodies propose methods to achieve high quality product development. The proposed models aim to achieve an *integrated* design, incorporating all the issues important to the design of a new product. Yet none of the models attempt to tackle the underlying problem, that being the lack of organisational integration. A possible exception to this criticism could be the work being undertaken in Denmark by Andreasen.

Andreasen's work on dispositions [23] stands out from the others as an attempt to tackle the integration problem at all levels of the organisation, using the product development process as a medium on which to focus. It is felt that by dispositions Andreasen means a *plan* [41] or as in the military usage *Stationing of troops ready for attack*, where the troops are the various functional groups and the attack is on the market place. If this is indeed what Andreasen is suggesting then it would represent, in the authors view, the first attempt in the literature to design integration into the organisation, through the use of integrated plans, and coordinating strategies centred around the product development process.

While research has been going on in the areas discussed above, another direction has been taken by yet another, very vast, group of researchers.

### **1.1.5 Computer Integrated Manufacturing**

In 1973 Merchant [42] proposed a system intended to bridge the integration gap and make United States Manufacturing competitive once more. Merchant's proposal was for a *Computer-Integrated Manufacturing system* (CIM) consisting of a:

*Closed loop feedback system, the prime inputs to which are product requirements (needs) and product concepts (creativity) and the prime outputs of which are finished products (fully assembled, inspected and ready for use). It is comprised of a combination of software and hardware, the elements of which include product design (for production), production planning (programming), production control (feedback, supervisory and adaptive optimising), production equipment (including machine tools) and production processes (removal, forming and consolidative, including assembly and in process inspection). It can be realised by application of systems*

*engineering and the digital computer and has the potential of being automated (by means of versatile automation) and of being made largely self-optimising (adaptively optimising).*

The computer-integrated system as proposed by Merchant is shown in figure 1.5.

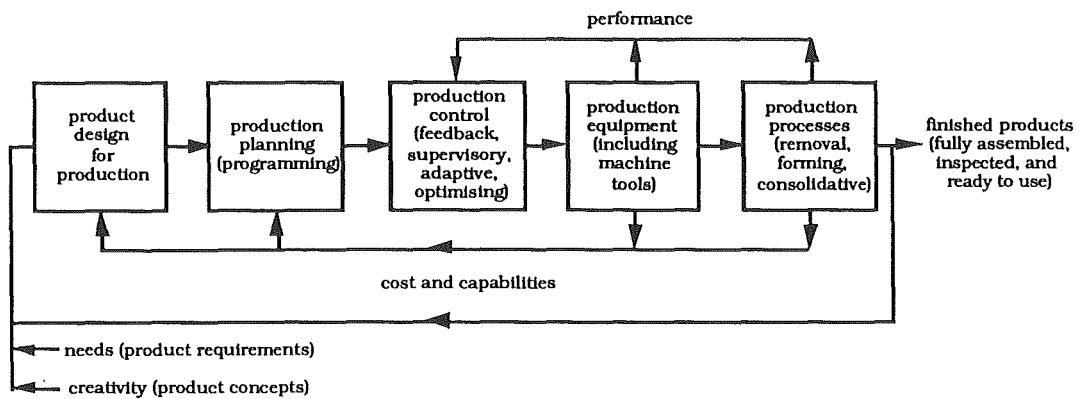


Figure 1.5 The Computer-Integrated Manufacturing System [From 42].

Since 1984 major advances have been made in some of the areas necessary for CIM, and a abundance of information has been written about it (mainly in the U.S.A.), however, it must be said that CIM *has not yet been achieved anywhere* [43]. The truth is that CIM may never be achievable, as Britton and Whybrew [10] assert, CIM is a fallacy, and it is the integration of systems through the human-computer interface that is likely to succeed. As they state it, computers do not integrate, but they can aid integration of people, thus CIM becomes CAIM or computer-aided integrated manufacturing. If CIM, as seen by Merchant, was achievable then the need for well designed organisations would be largely unnecessary, as all essential integration would occur through the CIM system. However, as indicated above it is unlikely that the level of integration considered achievable within CIM will ever occur. Consequently if successful product development is to take place a high degree of organisational integration will be needed, thus well designed organisations are a must.



### 1.1.6 Organisational Design

To design well integrated and effective organisations, it is first necessary to have a clear understanding of what the essential elements are that comprise such an organisation. To the author's knowledge the Viable System Model (VSM) [44,45,46,9], developed by Stafford Beer, is the only model that provides the necessary conceptual basis for effective organisational design. Beer's VSM is based on the concepts of cybernetics, a term which was defined in 1948 by Norbet Wiener as being *the science of communication and control of animal and the machine*, some years later Stafford Beer stated that Management Cybernetics was the *science of effective organisation*. Central to the concept of cybernetics is the principle of feedback; a backward flow of information that can be used to help steer the system concerned in a desirable direction. The power of Beer's Model lies in its applicability to any viable system, and the way in which it allows them to be seen as cohesive wholes, so that the adequacy of the strategies adopted by the system to cope with environmental complexity can be assessed [46].

The complexity of organisations and the generality of Beer's model means that the Viable System Model is not straight forward, as a result the model has received limited attention from academics and management practitioners alike. While this remains true it has received considerable attention from a small group of researchers such as; Raul Espejo [47,48,49], Markus Schwaninger [50,51] and Britton and McCallion [52]. This thesis is concerned with the integration of organisations; organisations by definition consist of a number of interacting individuals divided into groups of functional experts. Beer's Viable System Model will therefore be used for establishing the relationship between organisational functions, as they attempt to integrate for the effective operation of the firm as a system.

While the Viable System Model sets down the necessary and sufficient criteria for an organisation to be integrated and viable, it says nothing about how to ensure that the level of necessary integration is achieved within an organisation. It is obvious that

the most integrated solution to a problem, would result if a single multi-skilled individual, who possesses all the relevant information, makes the necessary and appropriate compromises, considering all the factors that affect the final decision to be made. This was the aim of the old apprenticing system used to train professional engineers, alas it exists no longer, and now integrated decision making requires the interaction of several skilled individuals. The interaction of these individuals is for the purpose of communicating their beliefs about the decision to be made: the problem that now exists is that of effective communication of those beliefs. Communication, as defined by Ackoff and Emery [53], as:

*One purposeful individual (B) communicates to another (A) when a message produced by B produces a change in one or more parameters ( $P_i$ ,  $E_{ij}$ ,  $V_j$ )<sup>7</sup> of A's purposeful state.*

Within this definition, Ackoff and Emery have spoken about one purposeful individual communicating with another purposeful individual. A purposeful individual, as defined by Ackoff and Emery, is someone who chooses their own objectives, and how they are going to achieve those objectives.

Thus an individual who is working on a production line, with no choice of objectives (except working or resigning), and no choice of how to achieve the objective, e.g. screw A goes in hole A, screw B in hole B, could not be considered a purposeful individual, while a person waiting to get home from work would be. Thus communication is the process through which purposeful individuals are able to integrate their beliefs about the structural and functional properties to be attained. Important to this communication process are three factors the first of which is syntactics.

- a     *Syntactics is the study of the rules which we use to combine signs and symbols together to produce messages (see list of definitions for meanings). An example of syntactics is the development of language protocols to allow computers to communicate.*

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<sup>7</sup> Where  $P_i$  is the probability of choice,  $E_{ij}$  is the efficiency of a course of action, and  $V_j$  is the relative value of an outcome.

- b. *Semantics is study of what signs refer to, their signification. For example a drawing may be the semantic representation of a machine for example, and finally*
- c. *Pragmatics is the study of the relationship between a sign, its source, and/or its respondent. Thus pragmatics is concerned with the meaning taken by the receiver of a message. If for example the receiver of a message associates a different meaning to words than the sender then the communication will have broken down at the pragmatic level.*

Hence for effective communication to occur the syntactics, semantics and pragmatics must be correct, else misunderstanding will occur. It is for this reason that verbal communication is not sufficient to guarantee the integration of beliefs, for individuals with differing life experiences.

## **1.2 Aim and Scope of Present Work**

The fundamental issue to be addressed in this Ph.D. thesis is that of integration, with particular emphasis on the integration of the hypothesis development process.

Reviewed in this introductory chapter have been the main areas of research in this field, this work has been used to gain a clear understanding of what issues are faced by modern manufacturers, and what a lack of integration really means.

While the writers in the product development arena offer some relief to managers in the manufacturing industry, the models they propose offer little more than their ideas, based on their years of experience, on how to tackle this very difficult problem. The very real problem with these models is that there appears to be no fundamental basis for the proposals that their authors make.

The aim of this Ph.D. is to put forward a model which is applicable at all levels of the hypothesis development process; from the design of the organisation to the determination of geometric form of the components that comprise its products. This model is based on the fundamental work of Ackoff and Emery, it also draws

heavily on the principles developed by Beer for his Viable System Model, while remaining consistent and compatible with modern design theory.

The remainder of the thesis develops the theory for the model and show how it can be used through the detailed analysis of a number of different case studies. These case studies range from the collapse of Rolls-Royce in 1971 to a fatal chemical plant explosion in England in 1974. As a very practical demonstration of the models use, in the design arena, a detailed analysis of the product development process used in designing a new freight container for the New Zealand Railways will be carried out. Also discussed is the logic of a possible control system, appropriate for the management of the hypothesis development system, using the *Purposeful Design Model*.

Before developing the proposed model the following two chapters will set the scene in terms of background theory and applicable definitions. Chapter two will provide definitions for such things as what integration and design really are, while also back grounding systems theory and how it applies to the design process. Chapter three will introduce Beer's Viable System Model and Ackoff and Emery's model of the purposeful individual, and how the two models compliment each other for the purpose of achieving organisational integration.

## CHAPTER 2

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### CONCEPTS AND DEFINITIONS

#### 2.1 Introduction

With research that depends on the vagaries of the written word, instead of the strict conventions of modern mathematics, it is essential to ensure that the pragmatic aspects of communication are consistent between the reader and the writer. In other words the meaning attached to particular words, by both parties, must be the same if the work is to be meaningful and of any use to the wider population of researchers.

Throughout this thesis a number of words have very definite meanings, to ensure that the reader attaches the same precise meaning, as intended by the author, those words will now be defined. To ensure that the definitions given to the words are consistent with modern usage, yet fundamental enough to hold in all operational situations, it was decided to adopt Ackoff's operational definition schema [54] for the purpose of defining the terms: Integration, Coordination, Designing and Planning.

#### 2.2 Operational Defining

It seems pedantic to spend time analysing and defining words that we use every day, however, the importance of defining is something too often taken for granted. As Ackoff states [54]

*Defining is an aspect of the research process which all too few scientists take very seriously. The meanings of the concepts are too often taken for granted. Yet definitions are essential as criteria for relevance of data used in evaluating variables and constants in all types of scientific statements: theories, laws, facts, and decision models... The progress of science, pure and applied, is as dependent on progress in defining as on progress in any other aspect of inquiry.*

The purpose of operational defining is to develop a definition which can be used as a yard stick in operational situations to

determine the true nature of a situation. For instance, if the layout of machinery in a factory is changed and as a result the factory's productivity improves, then has the change in machinery placement been an act of improved integration or improved coordination? Without clear operational definitions it would be impossible to say.

### **2.3 Ackoff's Operational Defining Procedure**

Ackoff provides a procedure for use in developing operational definitions, it has five steps and is as follows:

1. *Examine as many definitions of the concept past and present, as possible. Keep in mind the chronology of the definitions examined.*
2. *Try to identify the core of meaning toward which the definitions seem to be evolving.*
3. *Formulate a tentative definition based on this core.*
4. *Examine usage of the concept in the context of the and determine if the meaning you have formulated will serve the decision makers or research objectives. If not, make necessary revisions.*
5. *Submit the definition to as wide a critical appraisal as possible and make any justifiable revisions suggested by the criticism.*

The above procedure was followed when defining those words previously listed, except for step five which was excluded due to the time available and the scope of the work being undertaken.

The nature of the research being reported in this thesis is based within systems theory, as such the operational definitions to be developed will be in terms of systems concepts. These concepts will now be explained before developing the operational definitions.

What is a system? A system is generally considered to be a collection of activities or things that come together to produce some property or properties, that the constituent parts do not exhibit themselves. For example, four masses of plasticine

brought together do not constitute a system, as the larger mass has no properties beyond those of its parts, whereas the components of an engine, when assembled, produce a system that converts chemical energy into mechanical energy. The properties exhibited by the system that are not present in the parts are often referred to as emergent properties [33] i.e. properties that emerge from the creation of a whole.

In 1940 von Bertalanffy [55] drew attention to the fact that there were two main types of systems, those that are open to their environment and those that are closed. Throughout this thesis a system will be taken to mean an open system.

In the following section operational definitions for integration and coordination will first be discussed, these terms being fundamental to work in the area of systems theory. Designing will follow, this being defined so as to clearly establish the meaning of the term, and the relationship between design and the activities of a manufacturing organisation. Finally planning will be defined to ensure no confusion exists between an act of designing and one of planning. Designing and Planning will also be categorised as acts of integration or coordination to determine their systemic function within an organisation.

## **2.4 Operational Definitions**

### **2.4.1 Integration**

#### ***(a) Historical Definition of Integration***

Integration comes from the Latin word *Integration-em* and was used only in the sense of renewal or restoration to wholeness.

The Oxford English Dictionary defines integration in the following way:

1. *The making up or composition of a whole by adding together or combining the separate parts into an integral whole; a making whole or entire.*

From this definition the following can be stated about integration:  
*For integration to be possible there must be two or more elements or activities that can be brought together to constitute a system.*

### **(b) Modern Definitions of Integration**

The following definitions are a sample of how modern authors view the meaning of integration.

When discussing Organisational Behaviour, Buchanan and Huczynski [56] had this to say:

*Integration : was the required level to which units should be linked together and their degree of interdependence.*

In their book titled Organisation And Management [57] Kast and Rosenzweig also considered integration as relating to wholeness:

*Integration is defined as the process of achieving unity of effort among the various sub-systems in the accomplishment of the organisations tasks.*

Lawrence and Lorsch [58] in their early work on *Differentiation and Integration*, in connection with organisations, defined integration as:

*The quality of the state of collaboration that exists among departments that are required to achieve unity of effort by the the demands of the environment.*

The act of bringing interconnected parts together in the process of integration is elucidated by Cheng Hsu et al [59].

*A unifying information model drives the functionality of the entire manufacturing enterprise via a generic construct, thereby providing the interrelationships among the various manufacturing functions, such as marketing, accounting, product/process design, process planning and production. As such the model integrates the different views and knowledge of manufacturing objects at a conceptual level, as opposed to merely transmitting or translating data from one form to another.*



Although not explicitly stated by any of the authors, it seems clear that integration refers to the bringing together of parts to form a system.

### **(c) Essential Properties of Integration**

All definitions of integration have discussed the idea of inter-relatedness and the requirement for all the parts to be present so as to produce the desired outcome. Therefore,

**Integration:** *the act of creating systems, whether systems of elements, or systems of activities.*

The reason why integration is so important being captured by Ackoff [60]

*Performance of the whole depends critically on how well the parts fit and work together, not merely on how well each performs when considered independently.*

## **2.4.2 Coordination**

### **(a) Historical Definition of Coordination**

The origin of the word coordinate in English is uncertain but it is felt that it was probably formed independently, from Co- and the Latin word ordinare, as a parallel form to subordinate.

The Oxford English dictionary defines coordinate and coordination in the following way:

#### **a) Coordinate**

1. *To place or class in the same order, rank or division.*
2. *To place or arrange (things) in proper position relatively to each other and to the system of which they form parts; to bring into proper combined order as parts of a whole*
3. *To act in combined order for the production of a particular result.*

b) *Coordination*

1. *The action of coordinating; the condition or state of being coordinated or coordinate.*
2. *The action of arranging or placing in the same order, rank or degree; the condition of being so placed; the relation between things so placed; coordinate condition or relation.*
3. *The action of arranging, or condition of being arranged or combined, in due order or proper relation.*
4. *Harmonious combination of agents or functions toward the production of a result.*

The essence of these definitions is that coordination is the:  
Ordering of activities or things so as to produce a desired result.

**(b) *Modern Definitions of Coordination***

The following excerpts are a small example of how some authors use coordination in their writings.

To Amey [61] coordination concerned harmony of relations and the production of a specific result:

*Coordination concerns the harmony of relations between system components, or of functions, which result in functional maintenance and the continuance of some process.*

The idea of harmony of relations or orderliness were also expressed by Wortman and Luthans [62]:

*Coordination is a classical function of management. In general it refers to the job of ensuring that different organisational components mesh both in time and function - that is, the time at which one component performs must be appropriate to the requirements of the other, and the functions performed by that component must contribute to rather than conflict with or overlap other components,*

In *Management in Modern Organisations* by Hainmann and Scott [63], coordination was viewed in the following way:

*Coordination pertains to the synchronisation of the actions of people within an organisation.*

When discussing *The Management Process* Fox [64] had this to say:

*By coordination is meant the effective synchronisation of related activities so that common purpose may be realised expeditiously.*

Although the number of definitions, or views, different authors have regarding coordination is not vast the following essential properties may be extracted.

### **(c) Essential Properties of Coordination**

Firstly, all authors have been concerned with some sort of synchronisation or ordering i.e. the *correct* placement of one activity relative to another.

The concept of a system, although only explicitly stated by Amey, was also implied by several authors in terms of *the organisation*. Thus a second property is that the activities being ordered must belong to the same system.

If we take these two properties together and refer back to the definition of integration, and the idea that systems exhibit properties beyond those of the constituent parts, then we can define coordination in the following way.

**Coordination:** *Is the act of ordering, or arranging, elements or activities within an integrated set to produce a specific outcome.*

### 2.4.3 Designing

#### (a) *Designing Defined*

As a basis for the meaning of design, the definition given in the Oxford English Dictionary is provided:

#### *Design (sb)*

1. *A mental Plan*
  - (i) *A plan or scheme conceived in the mind and intended for subsequent execution.*
  - (ii) *A plan or purpose of attack upon or on.*
  - (iii) *Purpose, aim, intention.*
  - (iv) *The thing aimed at; the final purpose.*
  - (v) *Contrivance in accordance with a preconceived plan: adaptation of means to ends.*
2. *A plan in art*
  - (vi) *A preliminary sketch for a picture or other work of art; the plan of building or any part of it, or the outline of a piece of decorative work, after which the actual structure or texture is to be completed; a delineation, pattern.*
  - (vii) *The combination of artistic details or architectural features which go to make up a picture, statue, building, etc; the artistic idea as executed; a piece of decorative work, an artistic device.*
  - (viii) *The amount of picturesque delineation and construction; original work in a graphic or plastic art.*

#### *Design (vb)*

1. *To plan, purpose, intend*
  - (i) *To form a plan or scheme of.*
  - (ii) *To purpose or intend (a thing) to be or do (something).*
2. *To delineate; to fashion artistically.*
  - (iii) *To trace the outline of; delineate.*

- (iv) *To make the preliminary sketch of (a work of art, a picture, etc.)*

The definition of design can clearly be seen to overlap with that of planning (section 2.4.4) which of course it is not. However, design may well constitute a portion of the planning process as in the case of Ackoff's Interactive Planning schema.

Britton [65] also recognised the inconsistent use of the term designing and its confusion with planning and attempted to delineate between them. From an analysis of several authors views, on the issue of designing, Britton developed the following essential properties.

### **(b) Essential Properties of Design**

Britton saw that:

*One essential property of designing is that it is produced by a purposeful system*

he also saw that:

*The product of designing is a message connoting the essential properties of an object which does not exist when the design is produced.*

Two further properties that were also considered essential to the definition of designing and the activity of the designer were that:

1. *he must not be aware of the complete set of the properties in the design when he starts designing;*
2. *he must not perceive a set of properties in his environment while he is designing, such that this set and those properties he starts with make up the complete set given in the design.*

The distinction that can then be drawn between an act of designing and an act of planning is that to design is to determine some specific end state, or some set of desirable properties. While an act of planning is about how to get from the present state to that of the newly desirable end state.

### **(c) Designing - Integration or Coordination ?**

Designing as an organisational activity may occur at two different levels (with reference to Beer's Viable System Model). The first of these is at the level of system development. Here the requirements of the organisation are *integrated* through the product development process. An example of this type of designing would be a new aircraft.

The second type of design occurs at the level of the operational elements, here products are customised to individual customer requirements. This represents a coordination of the previously integrated design system<sup>1</sup>. Incorporating particular engines or avionics into an aircraft to suit a particular customer would be an example of design at the operational element level.

#### **2.4.4 Planning**

##### **(a) Planning defined**

The Oxford English Dictionary defines a plan in the following way:

##### *Plan (sb)*

1. *A drawing, sketch, or diagram of any object made by projection upon a flat surface, usually a horizontal plane.*
2. *A diagram, table, or program, indicating the relations of some set of objects, or the times, places, etc. of some intended proceedings.*
3. *A design, according to which things or parts of a thing are, or are to be, arranged; a scheme of arrangement.*
4. *A formulated or organised method according to which something is to be done.*

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<sup>1</sup> The system representing the organisational activities of design, marketing, finance etc.

### *Plan (vb)*

1. *To make a plan (something existing, esp. a piece of ground or a building); to delineate upon or by means of a plan; to plot down, lay down.*
2. *To make a plan of (something, esp. a building to be constructed); hence, to devise contrive, design (a building or other material thing to be constructed).*
3. *To devise, contrive, design (something to be done, or some action or proceeding to be carried out); to scheme, project, arrange beforehand.*

Britton felt Ackoff had identified the core meaning of planning when he stated *planning is anticipatory decision making*, further to this Ackoff stated:

*The decisions involved in it form a system of interdependent parts. Because this system is too large and complex to handle all at once, planning must be done in parts, and each part must be evaluated and re-evaluated in light of at least one other part. The system being planned for is part of a dynamic environment which is such that organisational performance is likely to deteriorate unless management intervenes in the process going on inside and outside the organisation.*

The concept of anticipatory decision making was also considered important by Argenti [66]:

*A better way to define planning is to describe it as the process that leads to a plan. A plan is a set of instructions to someone and the planning process ends when these are ready to issue.*

Clearly planning results from an understanding of the system being planned for and the inter-connectedness of the elements that (will) constitute the system.

### **(b) Essential Properties of Planning**

Britton [65] summarised the essential properties of planning to be:

1. *The producer of planning is a purposeful system.*
2. *The product of planning is a plan, which connotes the essential properties of a future course of action*

*(choice) of a purposeful system (goal-seeking system).*

3. *The planner must not be aware of the complete set of properties in the plan when he starts planning.*
4. *The planner must not perceive in his environment a set of properties such that these and the set he starts with make up the complete set given in the plan.*
5. *The minimal information a planner can start with is a reference projection and a wishful projection.*

### ***(c) Planning - Integration or Coordination ?***

This section is about the properties of planning and whether they represent activities of integration or coordination.

Planning is generally considered to consist of four major types, these being, tactical, operational, strategic and normative, the distinction between the various types is as follows.

#### *Tactical Planning*

This is essentially programming, or a plan based on a predetermined scenario. In the military sense this represents a tactic to be employed should a predetermined course of events occur, e.g. an aerial attack.

#### *Operational Planning*

Is concerned with developing plans for the on going operation of a system, with the aim of maintaining or improving its performance over time.

#### *Strategic Planning*

Strategic planning is the development of a strategy, in other words a longer term plan that aims to change the structure of a system. In the military sense this would include the development on new weapons.



### *Normative Planning*

Normative planning is concerned with the development of norms, thus a normative plan represents a guide-line of the systems values.

Previously we have defined:

***Integration:*** *The act of creating systems, whether systems of elements, or systems of activities.*

***Coordination:*** *Is the act of ordering, or arranging, elements or activities within an integrated set to produce a specific outcome.*

With these definitions clear the four planning levels can be categorised as follows.

### *Tactical Planning*

Tactical planning represents plans of action under particular conditions, its aim, therefore, is to *coordinate* the elements or activities of the system.

### *Operational Planning*

Operational planning concerns the operation of an existing system, it therefore represents a plan to maintain or improve the *coordination* of that system.

### *Strategic Planning*

The aim of strategic planning is to develop plans of evolution for an existing system. To achieve this, additional elements or activities must be *integrated* into the system over time, thus changing the systemic properties.

## *Normative Planning*

Normative planning aims to *integrate* the values of all the stakeholders of a system, into a guide-line for determining the suitability of proposed tactical, operational and strategic plans.

Throughout the remainder of this thesis the meaning attached to the terms above will be as has just been defined. From these definitions it is now possible to answer the problem posed earlier in the chapter, namely is re-organisation of equipment in a factory an act of integration or an act of coordination? Clearly, if the reorganisation does not allow the factory to do anything it was not capable of previously, then the act has been one of improved coordination. It has simply raised the firms actuality closer to its capability.

This chapter has introduced several concepts, firstly it discussed what a system was: how it produced emergent properties and how it was either open or closed. It then went on to define a series of terms, two of which are fundamental to the process of product development, namely design and planning. The remainder of this chapter will look at the process of designing and explain why it can be viewed as a system of activities.

## **2.5 Design**

Section 2.4.3 stated that there are two types of designing, the first of these occurs within an organisation at the strategic development level, while the second is performed at a tactical level, e.g. the customising of a company product for a particular application. Because the second type of design could be (and has been) performed by a computer, it is the design carried out for strategic purposes that will be dealt with throughout this thesis.

While the actual words used to describe the process of design varies from one author to another, the general theme appears to point toward design being a process containing a vast number of different activities and interactions, as Asimow [25] states it;

*Engineering design is a purposeful activity directed toward the goal of fulfilling human needs,... (it) almost always requires the synthesis of technical, human, and economic factors; and it requires the consideration of social, political, and other factors whenever they are relevant.*

Matousek [24] on the other hand writes that the:

*designer uses his intellectual ability to apply scientific knowledge to the task of creating the drawings which enable an engineering product to be made in a way that not only meets the stipulated conditions but also permits manufacture by the most economic method.*

He goes on to discuss the relationship between the designer and other individuals or groups within the organisation, who are important in moulding the way the designer designs a new product, he summarises the discussion with the figure shown below.

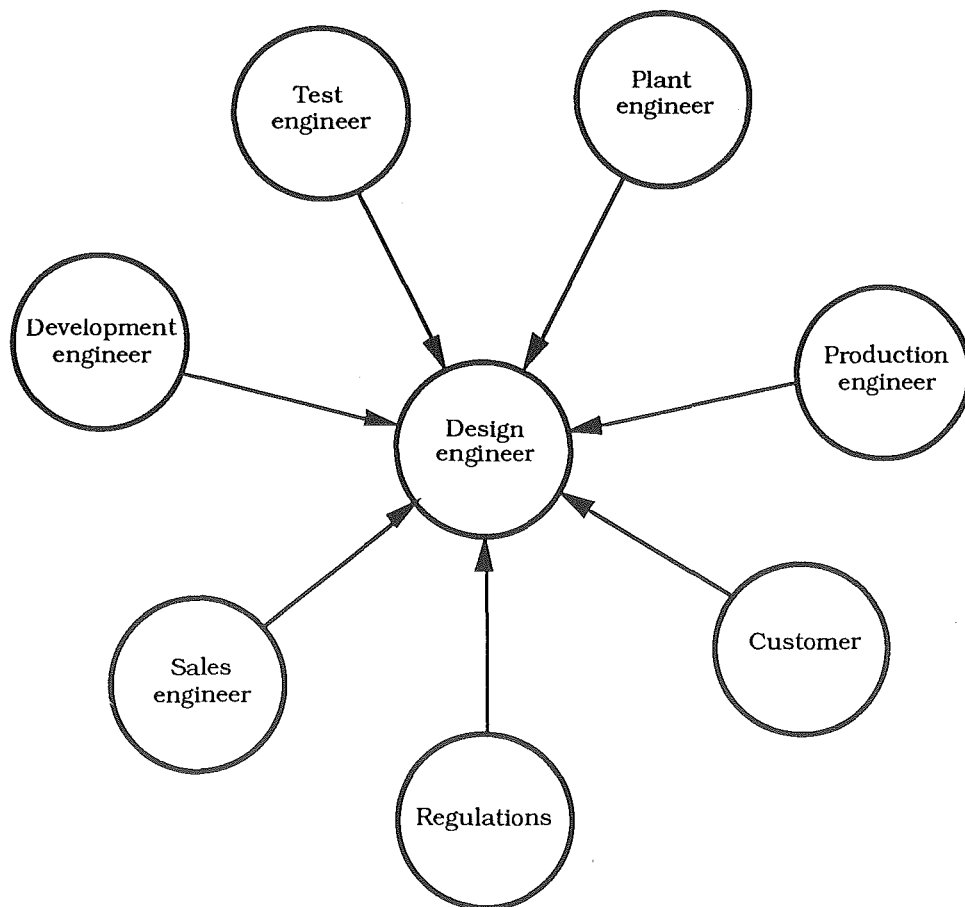


Figure 2.1 Relationship between the Designer and Others [After 24].

In his book titled *Principles of Engineering Design* [29] Vladimir Hubka simply states that;

*The design process contains a vast range of activities, which may be justified with respect to various disciplines.*

While Pahl and Beitz [28] state that;

*Designing is the optimisation of given objectives within partly conflicting constraints... designing plays an essential part in the manufacture and processing of raw materials and products. It calls for close collaboration with workers in other spheres. Thus to collect all the information he needs the designer must establish close links with salesman, buyers, cost accountants estimators, planners, production engineers, material specialists, research workers, test engineers and standards engineers.*

Finally Pugh [39] in his design activity model, figure 2.2 describes the design process as having a *central core*, the activity within the core being the result of an evolving *Product Design Specification* (PDS), the elements listed in the PDS (see figure 2.3) acting as a trigger for information-gathering and questioning at the beginning of any design activity [67].

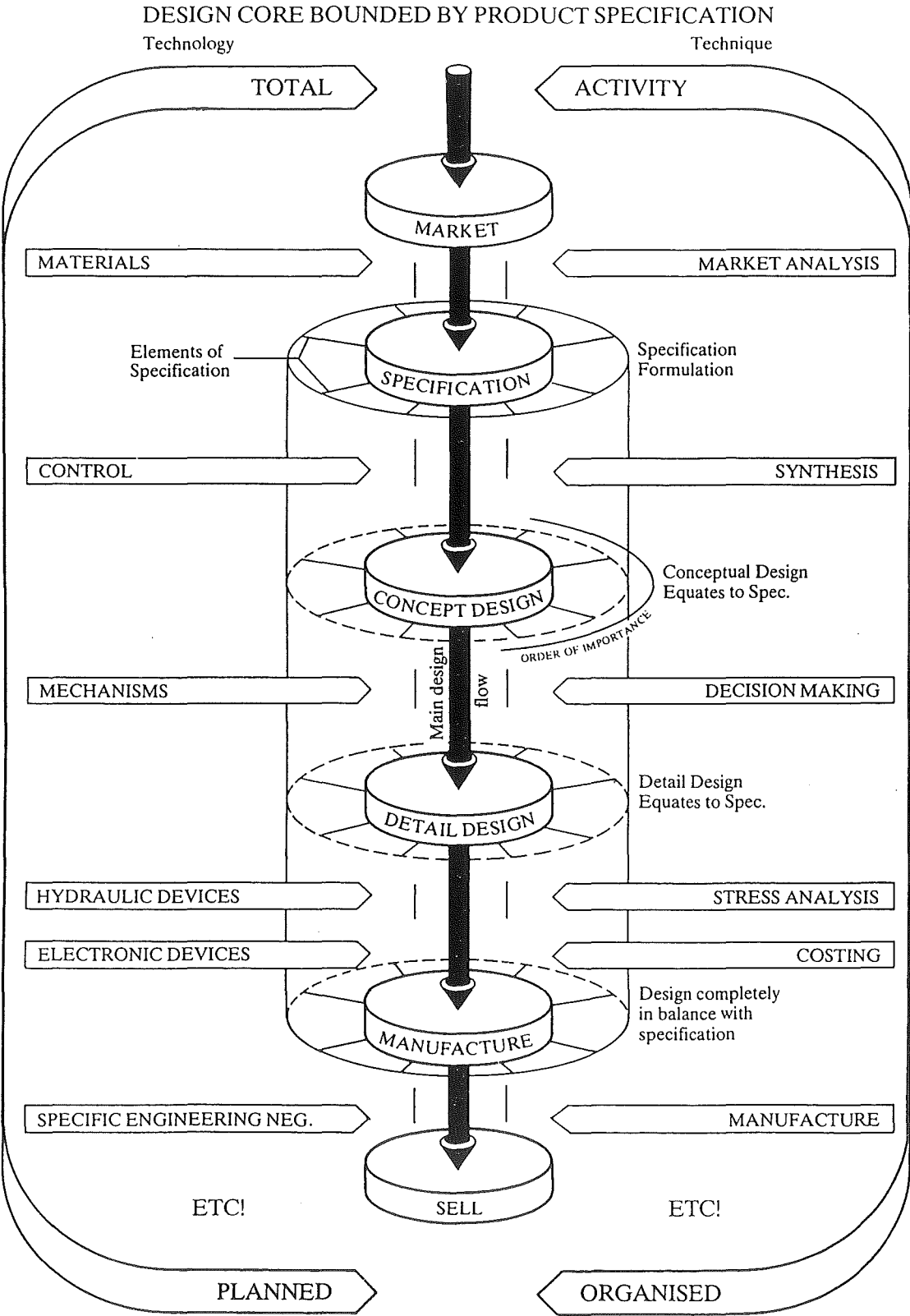


Figure 2.2 Product Design Activity Model [From 20]

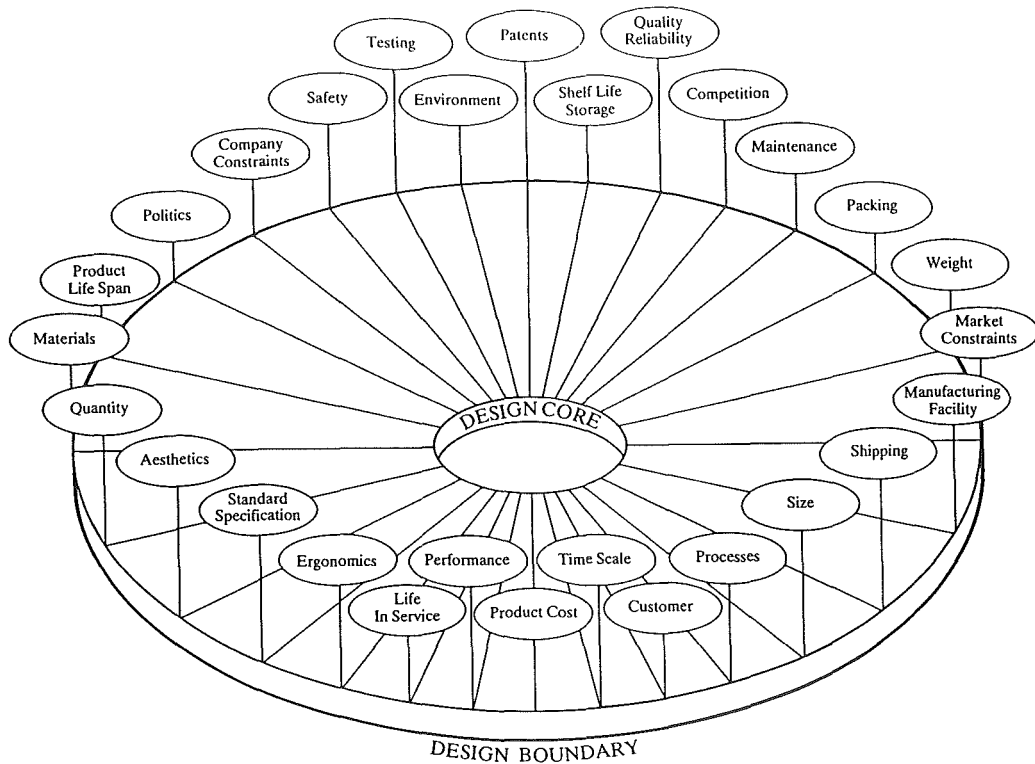


Figure 2.3 Elements of the Product Design Specification [From 20]

At the beginning of this chapter it was stated that a system is something that exhibits properties above and beyond those of its constituent elements. If any one of those elements is removed then the system fails to be the system it once was, accordingly the properties it exhibited by it will be diminished.

The process of designing is a system; take away any part of that activity and designing will not have occurred. Almost all authors about the design process would agree, that the process of designing includes, at the very minimum, a creative stage, where ideas are generated, and several subsequent stages where those ideas become more concrete. If any one of these stages does not occur then designing has not taken place and a new artifact cannot be produced.

But designing is more than just a creative exercise, it is a synthesis of environmental need and technological capability. The design process requires inputs to succeed, the more complete the set of inputs the more likely the product is to succeed in the market place.

A design represent a system of beliefs, beliefs about what is important for that product to satisfy the needs of the environment and the abilities of the firm. If a designer fails to take account of the beliefs held by say production, maintenance or even worse, the customer, then the design will lack properties that it should have had; the system will be missing some parts. The properties that it fails to exhibit may well be those necessary for it to find acceptance in the market place, or to stand it apart from its competitors.

Poorly designed products lack certain properties, poorly designed products don't sell, companies that cannot sell their products become insolvent. The benefits of well integrated product design are obvious, how to achieve it is not. The following chapter will now outline the two major theories to be used in this thesis and show how one is essentially a macro of the other.

## CHAPTER 3

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### INTEGRATED MODELS

#### 3.1 Introduction

Earlier in the introduction to this thesis, the *Viable System Model* as developed by Stafford Beer, and the work of Russell Ackoff and Fred Emery on *Purposeful Systems*, were introduced as being the backbone to the theories developed during the course of the project. Each represents an integrated model of systems capable of choice. While they are both suitable for diagnosing the actions of systems, whether they be individuals or complex organisations, it is Beer's Viable System Model that will be used throughout the remainder of the thesis for interpreting the structure of organisations; for the integration of the functions for the effective operation of the firm as a system. Ackoff and Emery's model, on the other hand, will form the basis of the model to be developed in the following chapter, that model concerning the integration of beliefs, necessary for the process of integrated hypothesis development.

#### 3.2 The Viable System Model

*Cybernetics is the science of effective organisation* [9]. Over about the last 30 years, Stafford Beer has taken that science and developed a model to unravel the complexities of modern organisations [44, 45, 46, 9]. Named the *Viable System Model* (VSM), it aims to specify the *minimum functional criteria by which a given organisation can be said to be capable of independent existence* [68]. To be independent, is to be able to withstand the rigours of a constantly changing environment without the guidance of some directing influence. We all become independent (possibly with the exception of the mentally impaired) at some stage in our lives, thus we, as individuals are fundamental to the model Beer developed. But earlier it was stated that the VSM is applicable equally to large complex organisations, herein lies one of the fundamental concepts of the VSM, the concept of recursion.



Recursion is the concept of invariant pattern, thus the Viable System Model is the same at any level of complexity, whether it be an individual or a large multi-national corporation. The model remains the same, the only change is the systemic properties being managed.

Recursion has been described as one of the fundamental concepts of Beer's model, an even more fundamental concept however is that of variety. Variety is a measure of the number of possible states that a system can achieve and is thus a measure of the systems complexity. But what is a state of a system? If you had a single switch, that could be set in either an on position or an off position, then you would have a system capable of two states; in other words it would have a variety of two. Two switches would have a variety of four and three would have eight. Thus it is easy to see that the variety of a system increases rapidly as the system becomes more complex.

Beer developed his model on the concept of variety, after the work of Ashby [69] and his Law of Requisite Variety. This law simply states that *only variety can destroy variety*, thus for a system to survive in a given environment it must generate sufficient variety to cope with that produced in its environment. To help in this process the system will develop attenuators between the environment and itself, it does this by filtering out unwanted variety. It will also design amplifiers between itself to the environment to ensure its effect on the environment is as is desired.

This is shown diagrammatically on the following page.

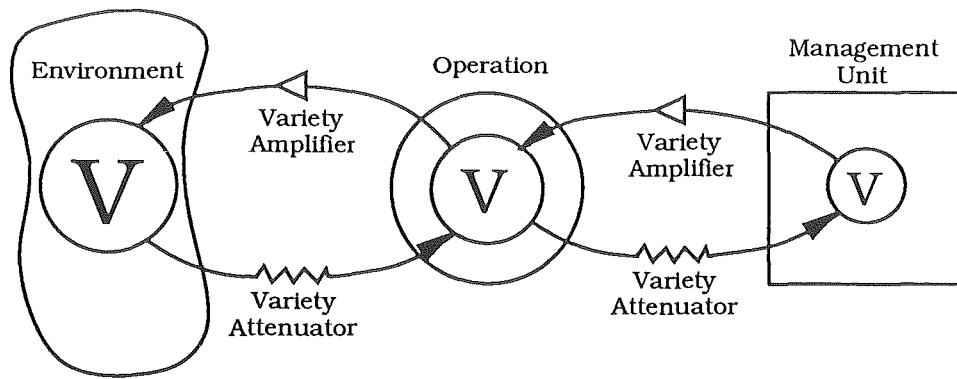


Figure 3.1 Attenuation and Amplification of Variety from Environment to System and visa versa [After 46].

The diagram drawn above, represents what Beer calls an *operational element* it is shown interacting with its local environment. Within any organisation it is likely that there will be a number of operational elements, each related in some way (after all they all come together to form a system) with intersecting local environments, as shown below.

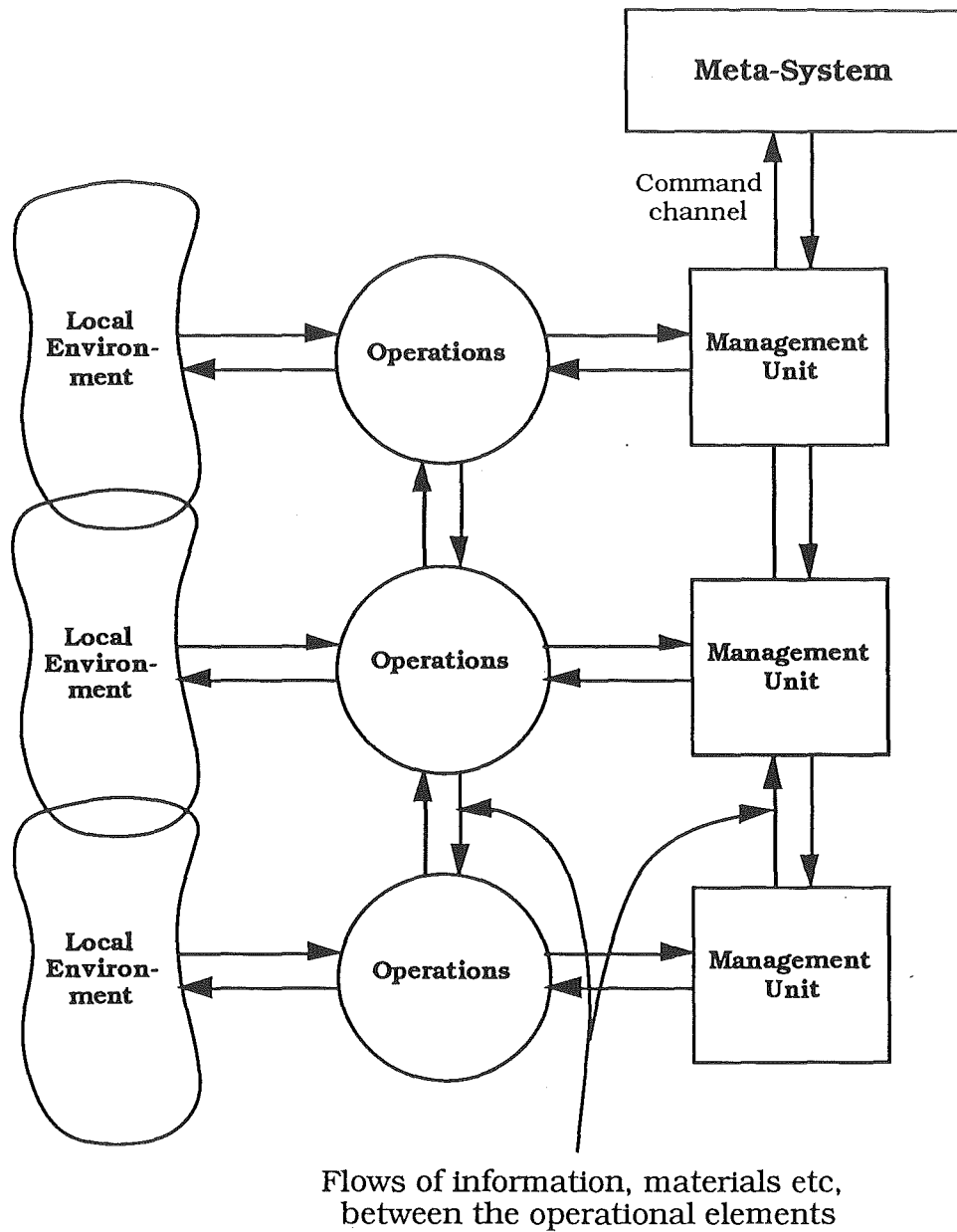


Figure 3.2 Interacting Operational Elements [After 46]

Because each of the operational elements represents a system in its own right, there will inevitably be instability in the interactions of the elements, due to their conflicting objectives, unless there is some higher managing authority. Beer includes such a management authority in his model, and refers to it as a *meta-system*. Its reason for existence is to *undertake whatever functions are required to procure coherence* [46] in the operational elements. Beer also argues the need for a meta-system on the basis of variety, with it absorbing any residual variety from the operational elements.

The relationship between the meta-system and the operational elements is shown in figure 3.3.

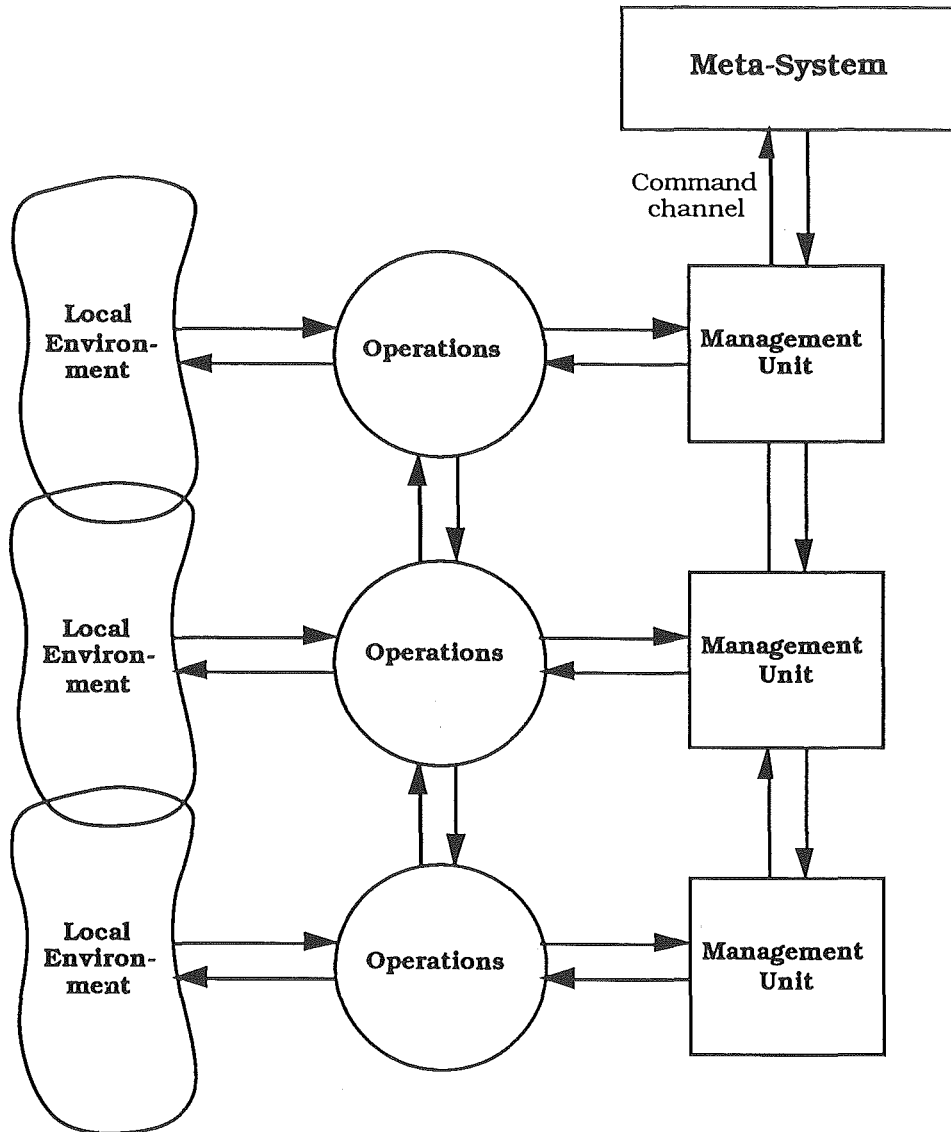


Figure 3.3 Relationship between Operational Elements and the Meta-System [After 46]

The meta-system aims for cohesion in the operational elements, that means ensuring that the elements act as a unified whole and not in an unstable manner. It could direct the elements on such things as when to act and how to act, but doing this would deprive the elements of their autonomy. While direction of this type may occur from time to time, an anti-oscillatory, or coordination type interaction with the elements is to be preferred. Beer's model includes a communication channel for such an interaction. Called System 2 (the Operational elements are referred to as System 1),

its role is to coordinate the activities of the elements so as to achieve overall system synergy. A time-table is an example of the sort of tools used within System 2. Figure 3.4 shows the emerging model.

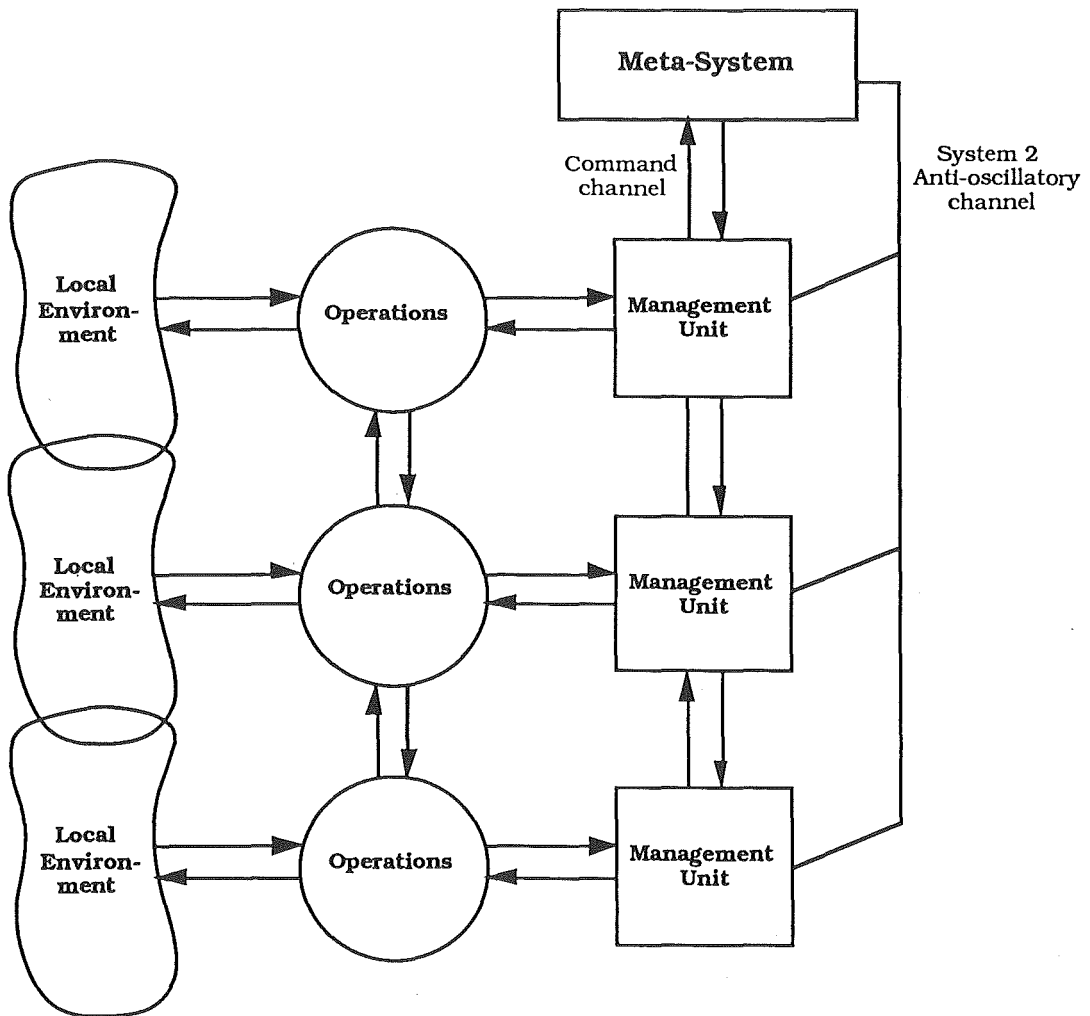


Figure 3.4 The emerging model [After 46]

To ensure that the resources provided by the meta-system to the operational elements are used correctly, and to monitor the performance of the elements, the metasystem employs a sporadic audit channel. An example of this type of auditing is the customer satisfaction audits performed on all McDonalds restaurants. In this case members of the public are recruited by the corporate level of McDonalds, these individuals are paid to buy McDonalds food in return for furnishing a report on the quality of service, food and presentation. Through this system McDonalds can monitor its

operations performance, as well as using the feedback to improve its overall system performance.

This auditing channel is known as System Three Star (3\*) and is shown below.

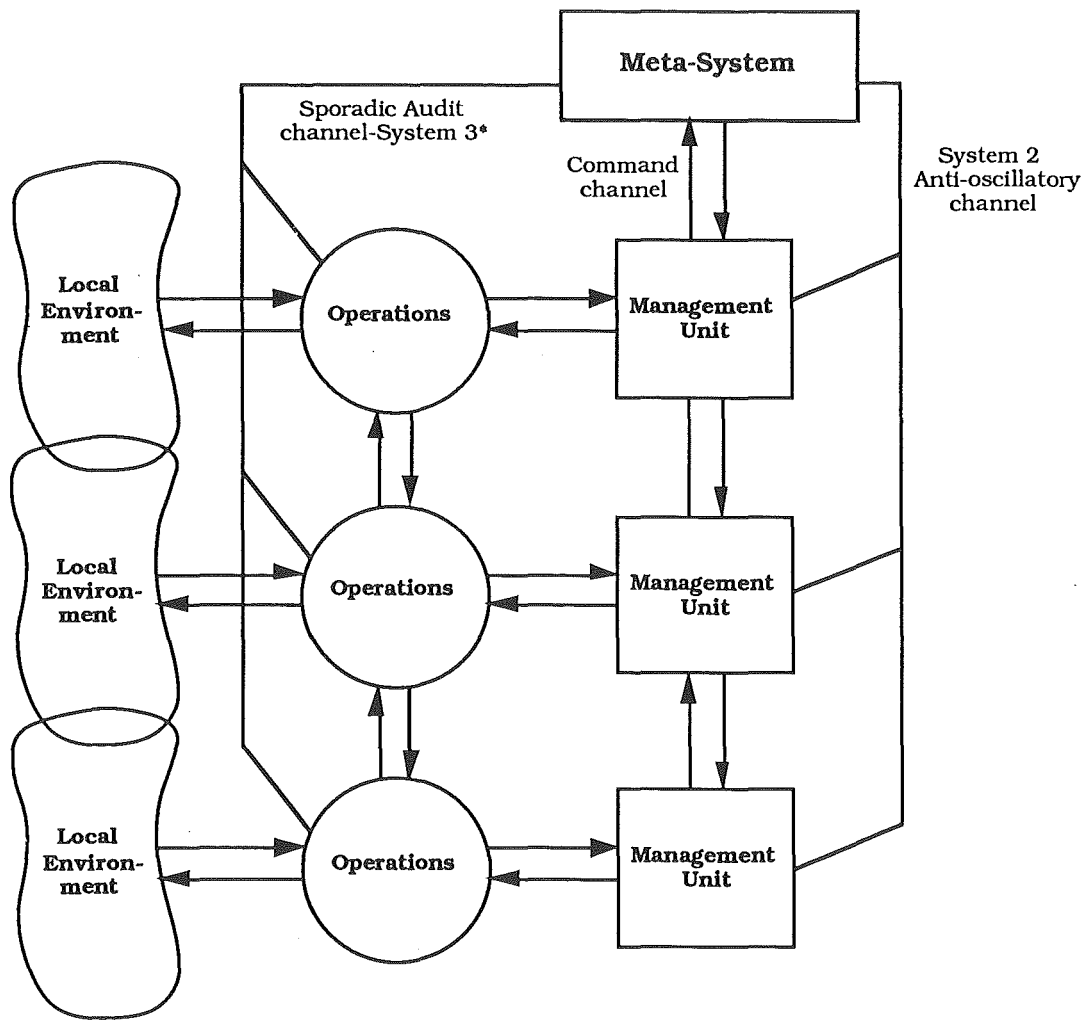


Figure 3.5 Operational Elements, Meta-System and Communication Channels [After 46]

To this point the metasystem has been described as a higher level management authority, and its functions have been largely undefined. It has been said that it aims is to maintain stability between the various operational elements. It does this through the use of the coordination channel (system 2), and the performance monitoring channel (system 3\*). The scope of the metasystem is, however, wider than this, its full role will now be discussed.

Why is a metasystem required? Would not it be possible to remove the instability, caused by the interacting elements, by requiring each of the elements to consider the good of the overall group, and thus compromise their individual situations for the benefit of the whole? This could well happen, and often would, but as soon as the participants (if more than one person comprises the viable system) of the various elements start talking about the instabilities, with an eye to overcoming them, they are in fact acting in the role of the meta-system. Acting in this way they are no longer just considering themselves, they are considering the emergent properties of the interacting elements. Thus the metasystem is concerned with the emergent properties of the elements.

The metasystem is comprised of three components, each with a very different focus. The first is concerned with what the system is, while the second develops plans regarding how the overall system should be developed over time. Finally the third component of the meta-system considers the identity of the entire system and acts to develop the systems ethos.

The first of these components is known as System Three, its purpose being to maintain and improve System One toward its potential capability. To do this, it needs the overall view of the interacting operational elements discussed above. It communicates with System One through the channels described earlier, namely System 2, System 3\* and the command channel. System 3 is totally introspective, and as such has no concern with the future development of the system, its planning horizon is in the short term. In Beers terminology System Three performs the *Inside and Now* function. While three is looking in, System Four is busy looking out; out into the contextual or known environment, and out into the problematic or unknown environment. System Four models the two environments and in parallel models the organisation, in this way it can see how to match the organisation to the changing environment.

While System Three is busy improving the actual performance of System One, System Four is busy working on how to improve the overall system capability toward its ultimate potential. Thus

System Four is responsible for the development of all of the viable system, whether it be System One, Two, Three, Three Star or Four itself. The type of company activities that could be modelled at the System Four level include; product design and development, marketing, finance, business planning and organisational development. For an effective System Four all of these activities must be properly integrated, the additional purpose of the overall system model at four, is to act as a focus for the planning that takes place within these different functional activities.

The purpose of Systems Three and Four are quite different, Three wants things to stay the same, and thus enable it to learn how best to manage the interactions of the various System One's, while Four desires change, so that the overall system is capable of matching what it sees the future environment requiring. It is obvious that Three and Four may have quite incompatible requirements, however, it is desirable that they reach agreement, i.e. to compromise their respective requirements. Unfortunately this will not be possible at times, and thus another system is required to ensure that the instability is resolved.

This system is known as System Five and its prime role is the stability of the three-four interaction, this it must achieve while protecting the identity of the organisation. In theory it does this by being constituted from the ranks of all those who contribute to the system. In practice, however, the stakeholders are represented by a single individual (the boss) or a group (the board of directors).

All the sub-systems that comprise Beer's Viable System Model have now been defined, as has the concept of recursion which enables one complete set of sub-systems to be linked to the set above. The full version of the model is now shown for two complete levels of recursion.



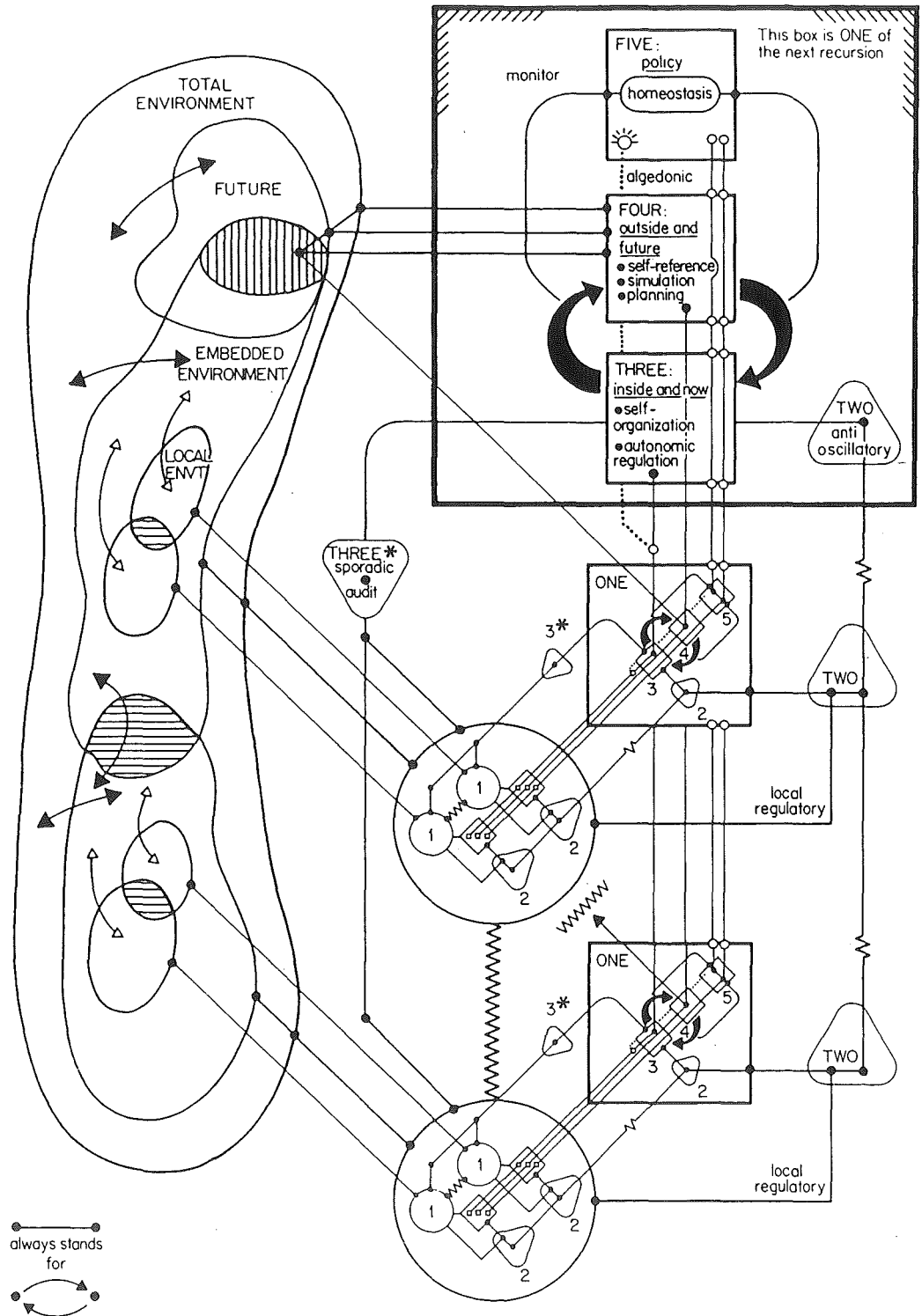


Figure 3.6 The Viable System Model [copied from 9]

The description of Beer's model, given here, is far from complete, for a complete understanding of the model Beer's own books [44, 45, 46, 9] should be referred to. However, additional to the above outline, a more complete description is given in Appendix A. This has been reprinted at the permission of Dr. Graeme Britton, who developed the notes for teaching in the final year engineering paper titled *Engineering Organisations*, taught at the School of Engineering, University of Canterbury, New Zealand.

The Viable System Model is one of the theories to be utilised within this project, another which became the basis for the theory developed, was Ackoff and Emery's Theory on Purposeful Systems [53]. It is now outlined here briefly for the reader.

### 3.3 The Purposeful System

The word *Purposeful* has now been used several times in this thesis, so far it has remained undefined. The purpose of this section is to define the meaning of the concept purposeful, and briefly outline the model developed by Ackoff and Emery for looking at such systems. In their book titled *On Purposeful Systems* [53], Ackoff and Emery define a *purposeful individual or system* in the following way:

*Purposeful individual or system: one that can produce,*

- a the same functional type of outcome in different structural ways in the same structural environment, and*
- b. can produce functionally different outcomes in the same and different structural environments.*

They go on to explain this in more everyday terminology:

*Thus a purposeful system is one that can change its goals in constant environmental conditions; it selects goals as well as the means by which to pursue them. It thus displays will. Human beings are the most familiar examples of such systems.*

The essential characteristic of purposeful behaviour is the ability of an individual or system to exhibit choice, choice over the objective selected and choice of the means by which to achieve it.

Shown diagrammatically a purposeful individual or system could be drawn as follows:

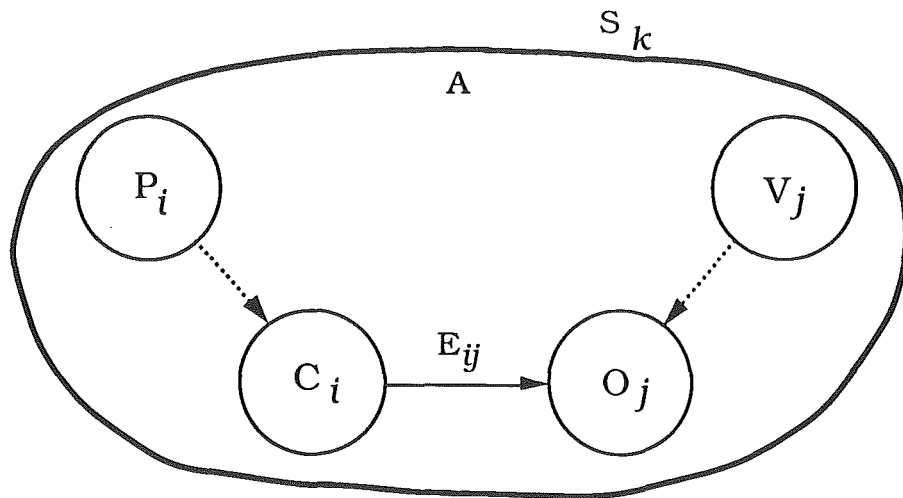


Figure 3.7 Diagrammatic Representation of the Purposeful System Model

- where
- A: is the purposeful individual or system.
  - $S_K$ : represents an individuals particular choice situation i.e. general area of interest.
  - $V_j$ : represents the probability of selecting a particular objective/outcome.
  - $O_j$ : is the objective/outcome.
  - $P_j$ : is the probability of selecting a particular course of action i.e. the means by which to achieve the objective/outcome.
  - $C_j$ : represents the course of action to achieve the desired result.
  - $E_{ij}$ : is a measure of a person's efficiency in using  $C_i$  to achieve  $O_j$  i.e. it represents their skill.

The concept of a course of action is something that is often confused, Ackoff and Emery state:

*A course of action is not to be construed as mechanistically conceived or physically defined action, but rather a morphologically<sup>1</sup> defined action.*

What this really means is probably best understood by looking at an example. Consider a designer who needs to design a bracket to withstand a given level of load. The courses of action available to him are not all the possible shapes of the bracket, but rather all the different ways of determining such things as the minimum cross-section necessary to achieve the desired result. Therefore, the courses of action would include; simple calculation, complex analysis and use of a finite element programme. The difficulty faced in determining the available courses of action, is that as the choice situation changes so do the available courses of action. Thus, what may have been an available course of action in one situation, may not be in another.

In the brief example detailed above the selected objective would be the set of structural and functional properties appropriate to the design of the bracket.

The brief description above essentially outlines the model as it stands, all that is now left to discuss is why purposeful individuals or systems select certain objectives or courses of action.

### **3.3.1 Beliefs and Feelings**

We all decide to travel to work each morning; by one particular means or another. We believe that, that means is preferable to some other, else we would choose the other. Thus each of use have beliefs about the courses of action which can be selected in achieving a particular outcome.

Our beliefs about courses of action include; what courses of action we have available to us, along with the efficiency we believe them to have in achieving the desired outcome. For example, in

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<sup>1</sup> *Morphological Property*: a set of physical properties [53].

deciding to go to work in the morning our objective is to travel from home to our place of employment. We believe that our options include, driving a car, taking a bus, travelling by bicycle or walking, we also believe that each of these have certain efficiencies. For instance, if we are required at work by 9.00am and it is already 8.30am then only some of the possibilities would be appropriate. The next bus may not be until 8.55am, its efficiency would be very low, the bike has a flat tyre, its efficiency would also be low. It is 10 km to work, so walking is not an option. Finally the car is available and serviceable so we would believe this to be our best option, and would thus select it in preference to the others. Beliefs about courses of action, therefore, act to raise or lower our probability ( $P_i$ ) of selecting them.

Beliefs about outcomes or objectives are also important to a purposeful individual or system. The decision to do something is based on the belief that it is preferable to the other options. Take again the example of going to work, it is our beliefs about the benefits of working (such as income or mental stimulation) that make us select this as opposed to staying at home or going on holiday. Thus beliefs are fundamental to the decisions we make, if you don't have a belief about something then its probability of being selected is zero. The courses of action or the outcomes will still be available to us, but they will never be selected due to our lack of a belief. In the same vein, if our belief about a course of action or a particular objective is ill-conceived then its chances of being selected at the most appropriate time are also low. Thus it is through the system of beliefs that people can be influenced, the lack of a true and appropriate set of beliefs means the likelihood of making bad decisions is high, while a broad set should reduce that possibility.

While beliefs enable us to make decisions, feelings influence our willingness to make particular decisions. Ackoff and Emery define a feeling as:

*To have a feeling is to be in a state of satisfaction or dissatisfaction.*

Within this definition exists two teleological<sup>2</sup> concepts, *attitudes* and *moods*, where;

*Attitude: An attitude is a feeling about something that persists over time and a variety of environments, and*

*Mood: A mood is a relatively short lived feeling that includes everything or most things experienced during that period.*

With regard to attitudes they add:

*Thus an attitude is a directed feeling, one that is produced by its object, such as an attitude toward a particular person, organisation or event. Hence one individual can have a hostile attitude toward another, and it will persist over time and manifest itself in different environments... it involves satisfaction or dissatisfaction and hence lends itself to dichotomous characterisation as favourable, unfavourable-unfavourable, for-against, like-dislike.*

So while an individual can have a belief about something that is favourable, an adverse feeling toward a *person, organisation or event* may make him act as if his belief was otherwise. For instance, if an individual wanted to travel to work, and the only means of transport available to him were taking the bus or walking, then he may choose to walk even though the bus is more convenient simply because he has an unfavourable feeling toward the bus company. This situation could also occur between individuals, and often does if a personality clash occurs. Such a situation could result in individuals acting in a way inconsistent with their beliefs, simply because of their feelings toward that individual.

Incorporating beliefs and feelings into the model of a purposeful individual or system we can redraw the previous diagram, as shown below.

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<sup>2</sup> *Teleological*: doctrine of final causes, view that developments are due to the purpose or design that is served by them [41]

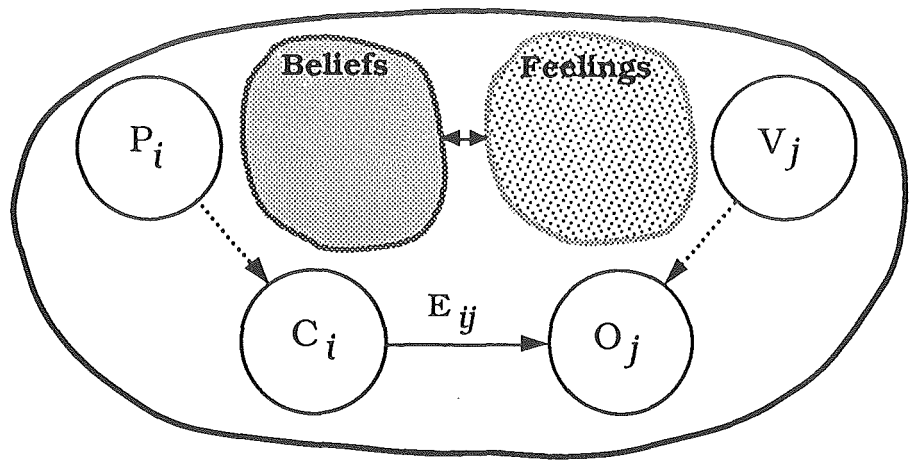


Figure 3.8 Beliefs, Feelings and the Purposeful System Model

The two way arrow between Beliefs and Feelings indicates that Beliefs influence Feelings and vice versa.

In a management situation, the effect of feelings should be able to be managed out of any interaction between two or more individuals, therefore, the purposeful system model will in these situations be represented as in figure 3.9.

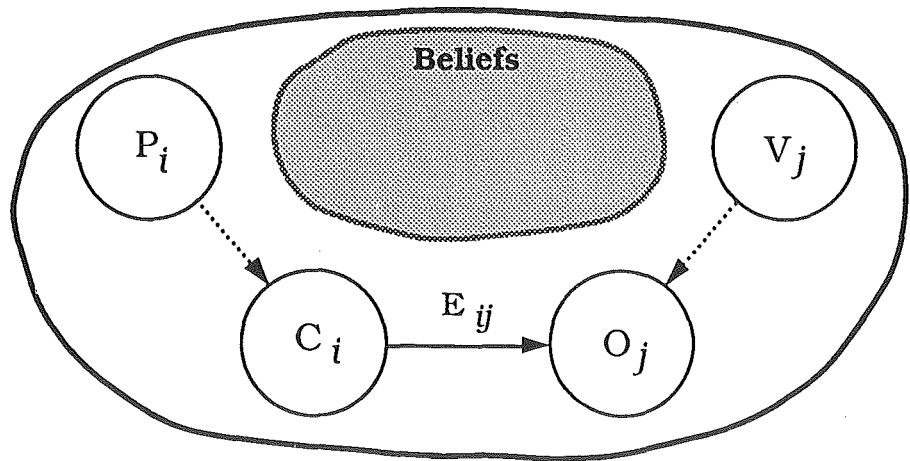


Figure 3.9 The Purposeful System Model as used in this Thesis

The description of Ackoff and Emery's purposeful system model has been necessarily short, a more detailed description is given in appendix B, which is a reproduction of course notes prepared by Professor H. McCallion for the *Engineering Organisations* course, discussed previously. The notes are reproduced here with the kind permission of Professor McCallion. The description in this

chapter or that reproduced in appendix B are, however, no substitute for the original work of Ackoff and Emery, titled *On Purposeful Systems* [53].

In the introductory chapter it was stated that the model developed by Beer, and that developed by Ackoff and Emery, are fundamentally the same. The following section will detail this point and discuss how when combined, the two models provide powerful tools for designing integrated social systems.

### **3.4 Integrated Systems**

At first glance it may appear that Ackoff and Emery's model has little in common with Beer's Viable System Model. In fact Beer's model was developed from an understanding of the neurophysiological constructs of a human being, while Ackoff and Emery's work is based in psychology. On closer scrutiny, however, the two models clearly describe the same fundamental criteria for an open system. Both of the models are about choice, choice to select objectives and choice to select the means to achieve those objectives. Each of them also discusses the need for identity and the role this plays in the choices that are made.

While the above statements remain true the two models do differ in the essence of what is described. The essences of Beer's model is that it describes the fundamental functional criteria required by an open system if it is to sustain itself, over time, in changing environments. While the essence of the Purposeful System model is that it describes a system capable of choosing the goals to be achieved and the courses of action to be adopted to achieve those goals in a given environment.

While Beer's work clearly discusses the environment, both contextual and problematic, it is only implied in Ackoff and Emery's work. They discuss the purposeful system in light of known environmental states. Thus by developing patterns of environmental behaviour, the purposeful system can learn to cope with changing circumstances. This point is supported by Emery



and Trist [70] who develop a classification for environments and discuss the interaction of systems within the different classes of environments. In three of the four environments defined (Placid Clustered,<sup>3</sup> Disturbed Reactive and Turbulent) it is necessary for the system concerned to be purposeful if it is to survive. At each level of environment/system interaction they consider the system requirements with regard to:

- (1) instrumentality;
- (2) planning;
- (3) learning.

They indicate that as the complexity of the environment increases, from placid random toward turbulent, the need for highly tuned planning and learning systems becomes essential.

This is consistent with Beer's requirement for ultra-stability and a system development function (system 4). The concept of recursion is also something that the two models have in common. While again Beer's model deals with it explicitly, Ackoff and Emery's model incorporates it through virtue of being a model of purposeful individuals, or groups of individuals. Thus while an individual is free to invoke choice, so is a group acting as one, only now the choices to be made concern the systemic properties of the group and not the concerns of a single individual.

We started this section by asserting that the two models are fundamentally the same, the arguments in support of this are given above, but it remains to be explained that there are two important differences between the two models.

The first of these is the difference in structure. Ackoff and Emery's model is largely descriptive and without clear form, while Beer provides a highly structured representation of his model, and as a result it is far more easily interpreted and usable. In fact Beer's work really represents a development of Ackoff and Emery's work, with an extension to describe how the system sustains itself in changing environments.

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<sup>3</sup> This only holds if more than one objective or course of action is available to the system.

The second difference in the models is due to their fundamentally different foundations. Beer's work has been developed using the neurophysiological model of the human being, and as such, the VSM is rich with control mechanisms and communication channels. While the purposeful system model is based in psychology and lacks such control systems, it does, however,

*Provide a way of looking at human behaviour as a system of purposeful (teleological) events [53].*

It is the structured nature of Beer's model, and its subsequent power as a diagnostic tool that has resulted in it being adopted, in this thesis, as a way of accessing organisational issues.

Organisational integration is the issue being dealt with in this thesis, and the interaction of individuals is fundamental to achieving it. For this reason, the Purposeful System Model has been adopted for interpreting the complex activities and interactions of the product development process. A process where the needs of a diverse system<sup>4</sup> must be synthesised into an integrated whole.

The next chapter will take the Purposeful System Model and use it to develop a model for integrated hypothesis development.

Note: In examining this thesis Dr. R. Espejo, of Aston Business School, Birmingham England, questioned the link between Ross Ashby's [69] theorem regarding models and the idea of beliefs. Ashby's theorem is stated eloquently by Stafford Beer [46] as:

*Every regulator must contain a model of that which is regulated.*

The author wishes to thank Dr. Espejo for making him aware of this connection and its applicability in the design process.

A model is a system of beliefs, the basis of the PDM is to ensure that the designer's beliefs (or models) are correct, the more correct the designers beliefs in the areas of client needs,

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<sup>4</sup> The system is comprised of the client and all of the functional activities that constitute the organisation.

organisational capabilities, technical design, and the environmental concerns of society, the greater the probability of the product finding acceptance in the market place.

Thus as a result of Dr. Espejo's query the author proposes the following theorem for design.

*To produce an effective design of an artefact a designer must have four integratable models, one each for the needs of the client, the capabilities of the organisation, the functioning of the artefact in its environments, and the environmental values of society in relation to its eventual disposal.*

By *effective* is meant; satisfies the client's structural and functional requirements: can be made, sold and distributed economically by the enterprise: can be operated reliably, and maintained economically in its working environment: and can be disposed of without damage to the environment.

The Purposeful Design Model through its designed interactions enables the designer to develop these models.

## CHAPTER 4

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### THE PURPOSEFUL DESIGN MODEL

#### 4.1 Introduction

Earlier in this thesis, it was stated that an ideal level of integration could only be achieved by a single, multi-skilled, individual, that individual having the required background of beliefs to make the numerous trade-offs necessary during a development project. It was also stated, however, that these multi-skilled individuals are no longer common, and that it is now necessary for the development process to rely on a group of interacting *experts*. Further to this statement, it was said that verbal communication was in general insufficient to ensure the necessary level of integration, the suggestion that it is sufficient, was called the *Fallacy of Functional Specialisation*. The true solution to the problem was said to lie in mapping one *conceptual space* on to another. The basis of this mapping requiring that the *semantic* and *pragmatic* aspects of communication are consistent between the individuals communicating.

In this chapter a model will be developed that allows a diverse set of beliefs to be incorporated into an integrated solution. The model ensures that the semantic and pragmatic aspects of communication are correct, it achieves this through a series of designed interactions; some to provide information and others to check that the information provided was used as intended. Based on the work of Ackoff and Emery, with significant conceptual input from Beer's Viable System Model, the *Purposeful Design Model* (PDM) has been developed to ensure that a designer has a *correct* set of *Beliefs* at all stages of the hypothesis development process.

Within Beer's VSM, System 4 is tasked with overall system development; product development is carried out to help ensure a future for the organisation and is therefore one of the System 4 activities. The elements of System 4 must be integrated effectively to ensure that that its output represents an integrated approach to the development of the viable system in focus [9]. The Purposeful

Design Model represents a system for achieving the necessary level of integration within System 4.

## **4.2 Background**

The initial basis for the PDM was proposed by Professor H. McCallion, who had developed a belief about the types of roles that needed to be performed if a design was to be produced with as few errors as possible. Professor McCallion had developed his belief from years of observation, yet had no fundamental basis for his ideas. While the initial model was without foundation, a degree of support for Professor McCallion's ideas were found with the discovery of a similar model. That model was proposed by Harlan Mills and reported by Brooks [71], its use was in the development of computer software, but its structure was virtually identical to that proposed by McCallion.

A slightly enhanced version of McCallion's early ideas are due to be published in the near future, in a joint publication with a former member of staff [72]. While the model that follows is based on the original ideas of McCallion, it has been modified and extended significantly, with each of the roles being founded on a fundamental requirement within the development process. To explain the way in which each role is integrated into the model, Ackoff and Emery's model of the purposeful individual or system is used to describe how each interaction influences the designer's beliefs in developing his design hypothesis. The way in which certain interactions provide information to the designer, to develop his beliefs, while other check the validity of those beliefs, ensures that the semantic and pragmatic aspects of communication are correct. The model consists of ten interacting roles, and is applicable whether the hypothesis development is being undertaken by a single individual, or a large multi-disciplinary group. The model as it has been developed will now be described.

### 4.3 Interaction Models

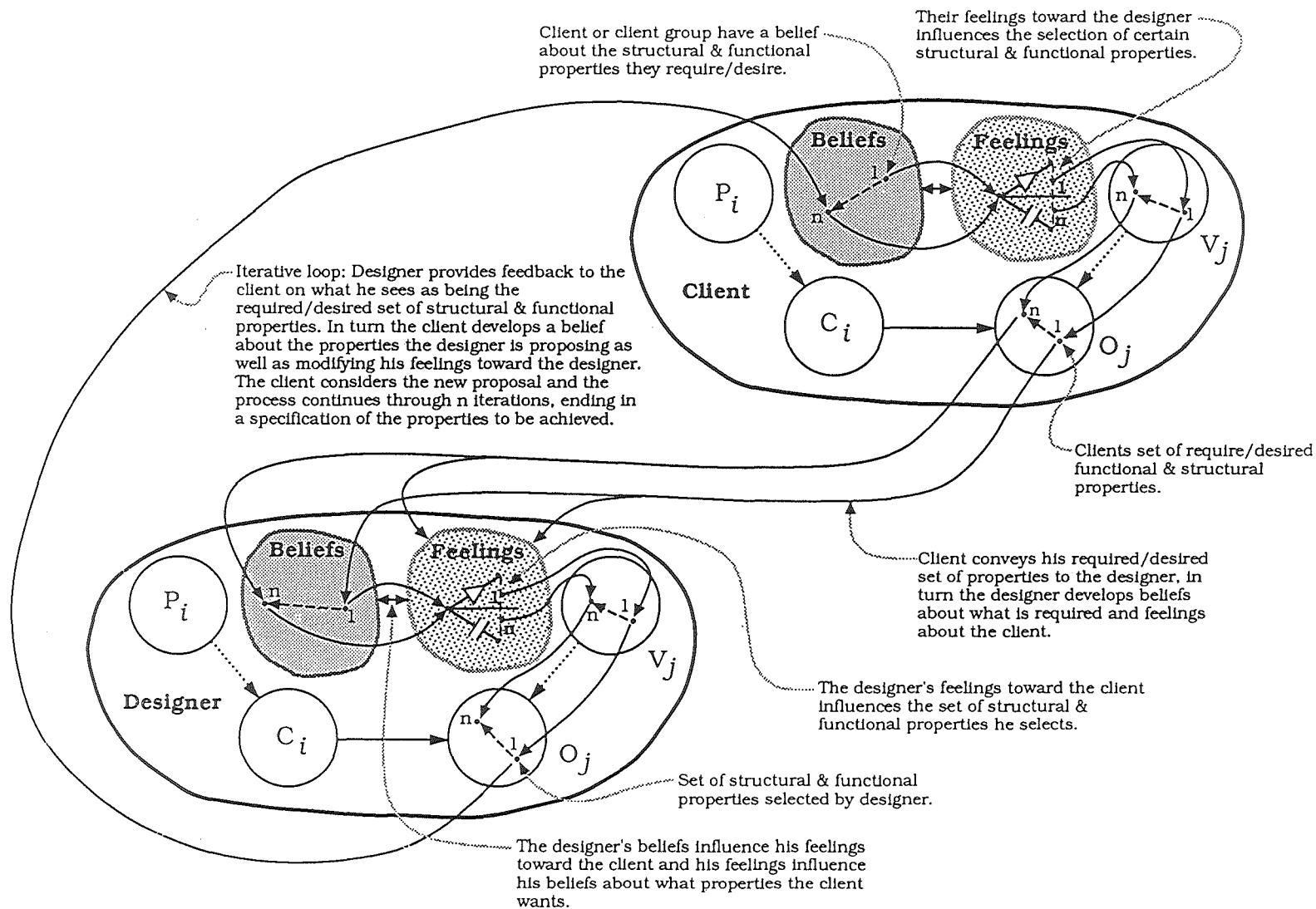
Central to the development process is the Designer, he is the developer of the design hypothesis and thus the integrator of a diverse set of beliefs. It is his task to develop a *fully* integrated belief about what is required (by the client or client group), and what the organisation is capable of supplying. Put another way, it is his role to integrate environmental need with the technical capabilities, and needs, of his organisation to the best of his ability. Fundamental to his role is understanding the need of the client or client group.

#### 4.3.1 The Designer - Client Interaction

Developing an understanding about the set of structural and functional properties required/desired by a client is paramount to the success of the development project. It is through *clarifying the task* that the designer is able to determine exactly what the client requires [24, 28, 29]. Figure 4.1 shows the purposeful interaction of the designer with the client, in the process of developing the set of structural and functional properties to be satisfied i.e. the design requirements.

In this diagram the influence of an individual's feelings toward the other individual or group (for example his organisation) is included. It is included because it cannot be managed out of the situation, for example a designer's ill feeling toward his client is something that has to be coped with, and must not be allowed to effect the final result. However, the feelings held by the designer and his client will normally be less extreme. For instance, a designer may consider that his client always understates or overstates his desired set of structural and functional properties. While the client may feel the designer is limited in his abilities, or conversely is able to provide anything he could possibly imagine. The effect of feelings in developing the final set of structure is shown in figure 4.2.

Figure 4.1 Designer - Client Interaction



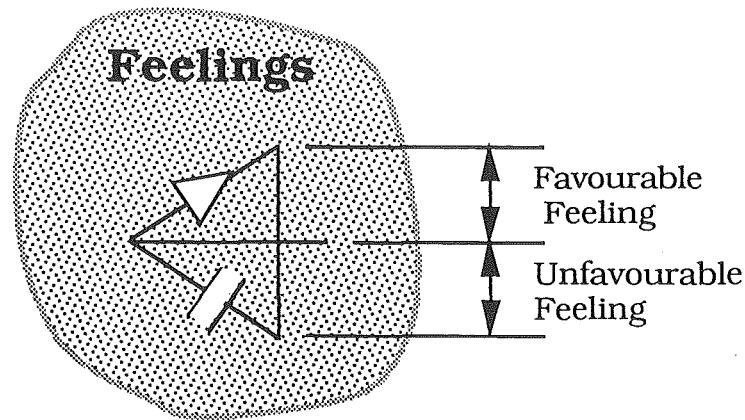


Figure 4.2 Feelings Mechanism

The amplifier symbol indicates a *positive* feeling toward the other individual, helping to reduce the number of interactions necessary to develop the final set of structural and functional properties to be achieved. The filter symbol on the other hand, represents a *negative* feeling toward the other individual, and acts to reduce the effectiveness of the interaction e.g. the designer may think his client is incompetent and as a result does not really know what he wants. As the process of developing the specification evolves each of the individuals feelings and beliefs are modified and in turn act on the other.

Isolating the set of structural and functional properties to be incorporated in the final artifact, starts with the client having a belief about what properties he desires or requires. His feeling toward the designer; designers in general; or the designer's company, act to modify the probability of selecting a certain set of properties. The client then communicates his desired/required set of structural and functional properties to the designer, who develops a belief about what it is that the client wants. This is influenced by what the designer feels about the client. He finally selects what he considers is an appropriate set of structural and functional properties to satisfy the clients need. The designer then feeds back to the client the set of properties he has selected. This feedback modifies the clients belief system and his feelings about the designer.



The process begins again with the client putting forward a slightly modified belief about what it is he desires/requires, this is again acted on by the designer and the process continues for  $n$  iterations. At that time the selected set of structural and functional properties is agreed between both parties and the hypothesis development process can continue.

Ultimately the client *closes the loop* between the designer and the environment, this he does by testing the result of the designer's hypothesis i.e. the artifact, in the *real world*. In doing this the client determines whether or not it satisfies his required set of structural and functional properties. By feeding this information back to the designer, the process of integrated hypothesis development becomes one of *integrated product development*. While this feedback loop is essential in discussions on product development, it will not be dealt with in this thesis, thus leaving the model as a generalised approach for situations requiring the development of hypotheses, such as designing, planning and diagnosing.

The designer is central to the hypothesis development process, if he is lost from the project the effort he has put into developing the specification, of what the clients requires or desires, may well be lost. To ensure this does not happen the designer must have a back-up, an alter-ego, someone capable of taking over should it be necessary. The following section outlines the need for such an individual.

#### **4.3.2 The Designer - Co-Designer Interaction**

It is not uncommon for a designer to have an assistant, someone who takes care of details for the designer. The co-designer is not someone like that, he is the designer's alter-ego, he to will also be a highly qualified engineer.

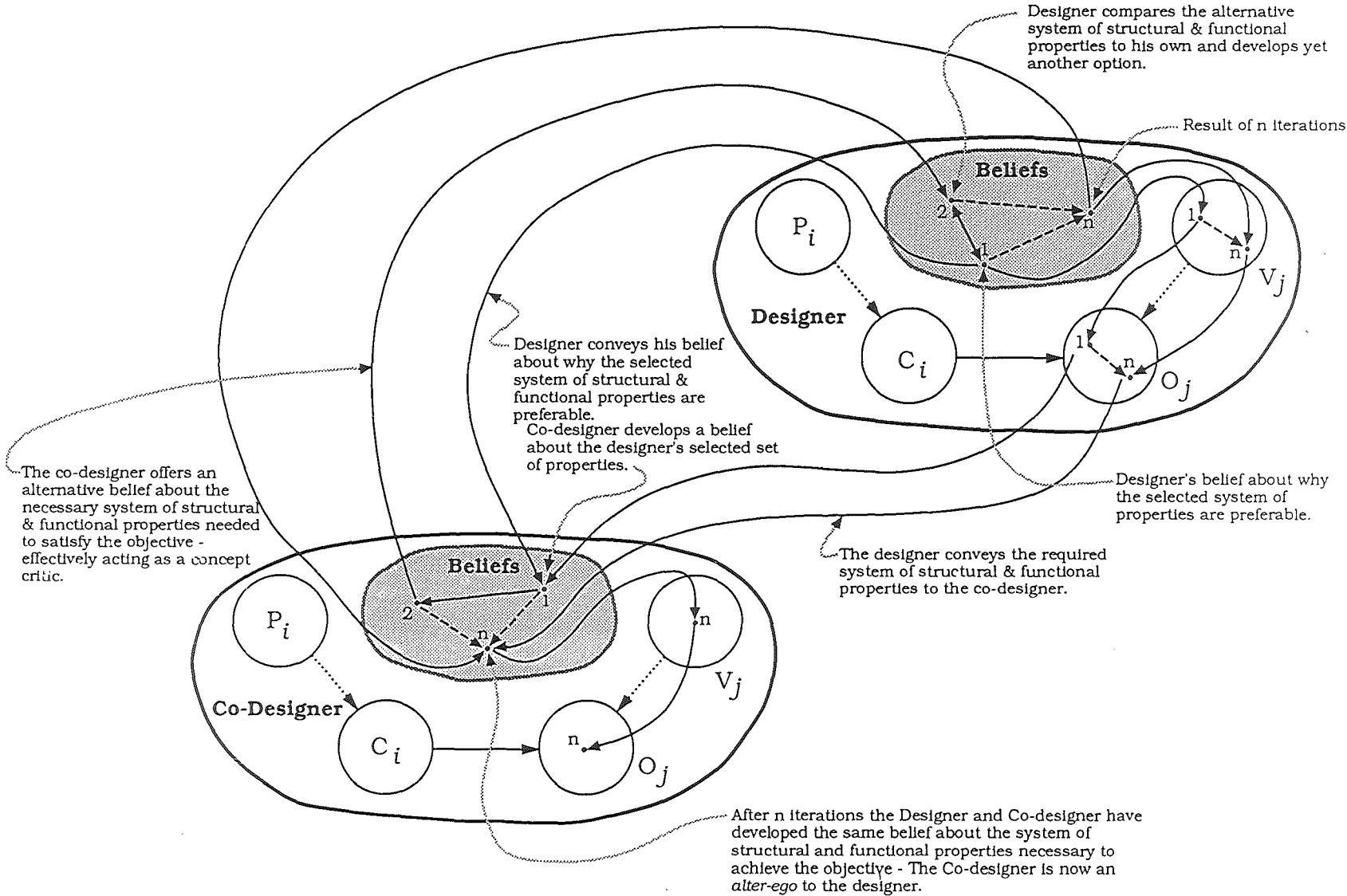
The co-designer must be working at the same intellectual level as the designer, as it is his task to take control of the project should the designer leave the organisation, or become incapacitated. The co-designer must be closely involved in the selection of the

structural and functional properties, in doing so he must develop the same belief as the designer about why the set of properties is desirable. The co-designer can also act to modify the designer's beliefs about the best set of properties; by acting as a *concept critic* to the designer, and proposing alternative view points. If the co-designer is unable to develop the same beliefs about the selected properties as the designer, then he will not be able to act in the role of *alter-ego*, and take over if required. It is therefore essential that the two work closely together to ensure they agree.

While the designer is busy with his task of ensuring the development of an integrated hypothesis, the co-designer may be assigned system studies, which may allow improvements in the design hypothesised. One further and final task of the co-designer, is to resolve conflict or instabilities between those involved in developing designs at lower recursive levels (this concept in relation to a development project will be discussed later). It is intended to relieve the designer of as much burden as possible, therefore, his alter-ego is tasked with resolving disputes at lower levels, leaving the designer free to work on integration of the hypothesis at his recursive level. Figure 4.3 shows the interaction of a purposeful designer with a purposeful co-designer.

The designer and his co-designer are central to the development project, that they have a common belief about the structural and functional properties required by the client is essential to ensure the completion of the project in unforeseen circumstances. Yet while the demands of the client are paramount to the success of the organisation, the abilities of the organisation to produce the artifact determine exactly what system of structural and functional properties the designer can ultimately specify. To be familiar with the organisation's capabilities, the designer must interact with various functional experts in determining the ability of the firm to satisfy the clients need.

## Designer - Co-Designer Interaction



### 4.3.3 The Designer - Functional Expert Interaction

A functional expert is someone who knows his specialist area, such as a production engineer, marketing representative, financial representative, or designer. Their role is to determine the current capability of the organisation and convey this to the designer. They must also be familiar with advances in their respective areas, so that the potentiality of the organisation can be extended should it be deemed necessary e.g. by the purchase of a new machine to perform certain, previously unavailable, tasks.

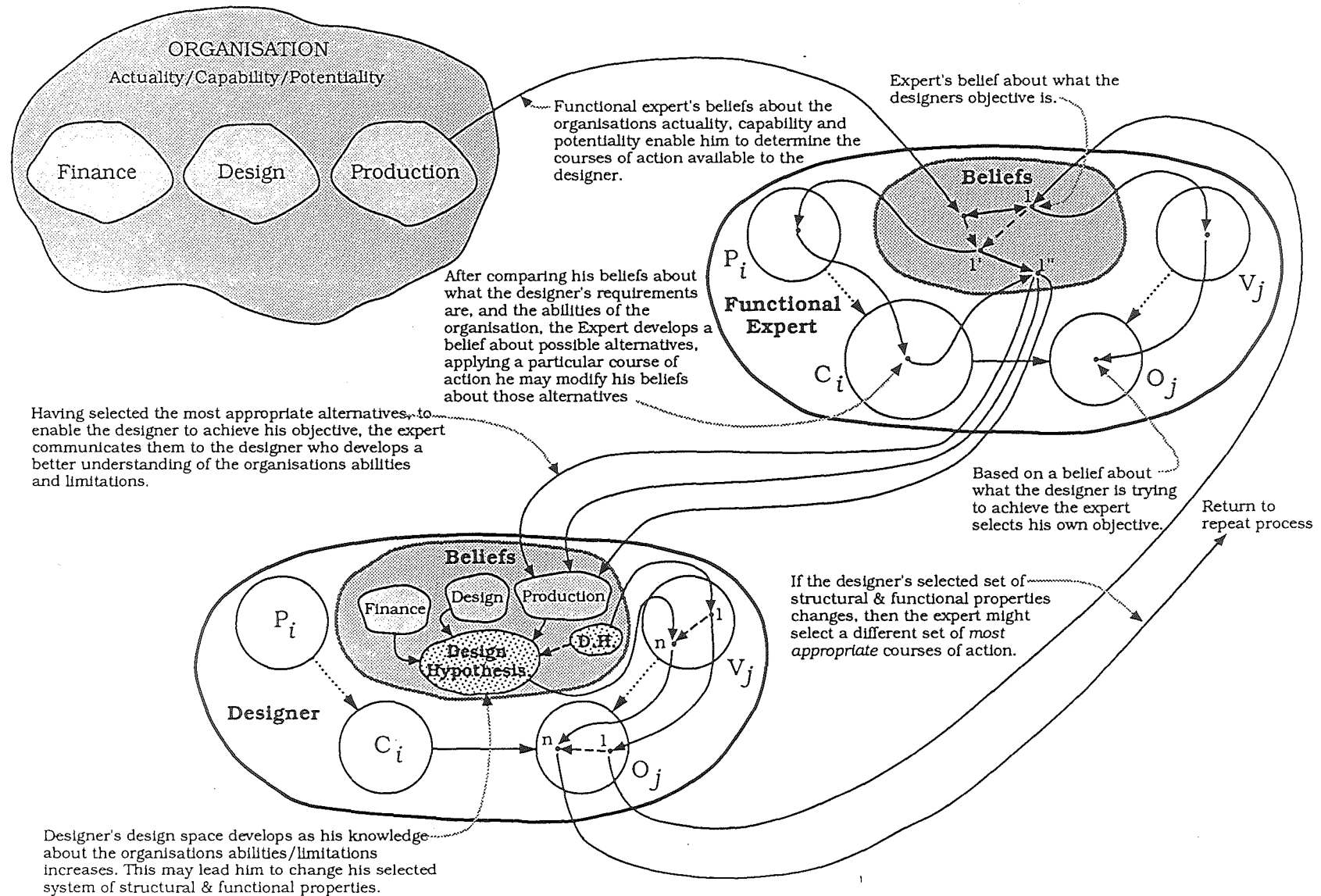
A number of authors such as Andreasen [27,23], Pugh [39] and Matousek [24], consider this role as essential to the product development process. From a purely logical stand-point, it is also clear that such a role is essential. Figure 4.4 shows the purposeful interaction between the designer and functional expert.

This interaction begins with the designer developing a *Design Space*; being his perception of the available solutions within the organisations capability. This must clearly relate to the set of structural and functional properties previously defined during the designer's interactions with the client.

The designer conveys his objective to the various functional experts, who develop a belief about the role their respective functions could play in the development process, and thus the options they can offer the designer. They convey to him all the possible *courses of action* available: this has the effect of expanding or constraining the available design space.

If the organisational capability desired by the designer is not available, it becomes a management decision whether or not to develop the potentiality of the organisation to make it available. It is through this interaction that a high degree of integration can be achieved, as it allows for plans to be drawn up by each of the functional specialties based on the same set of assumptions, namely those of the hypothesis being developed.

Figure 4.4 Designer - Functional Expert Interaction



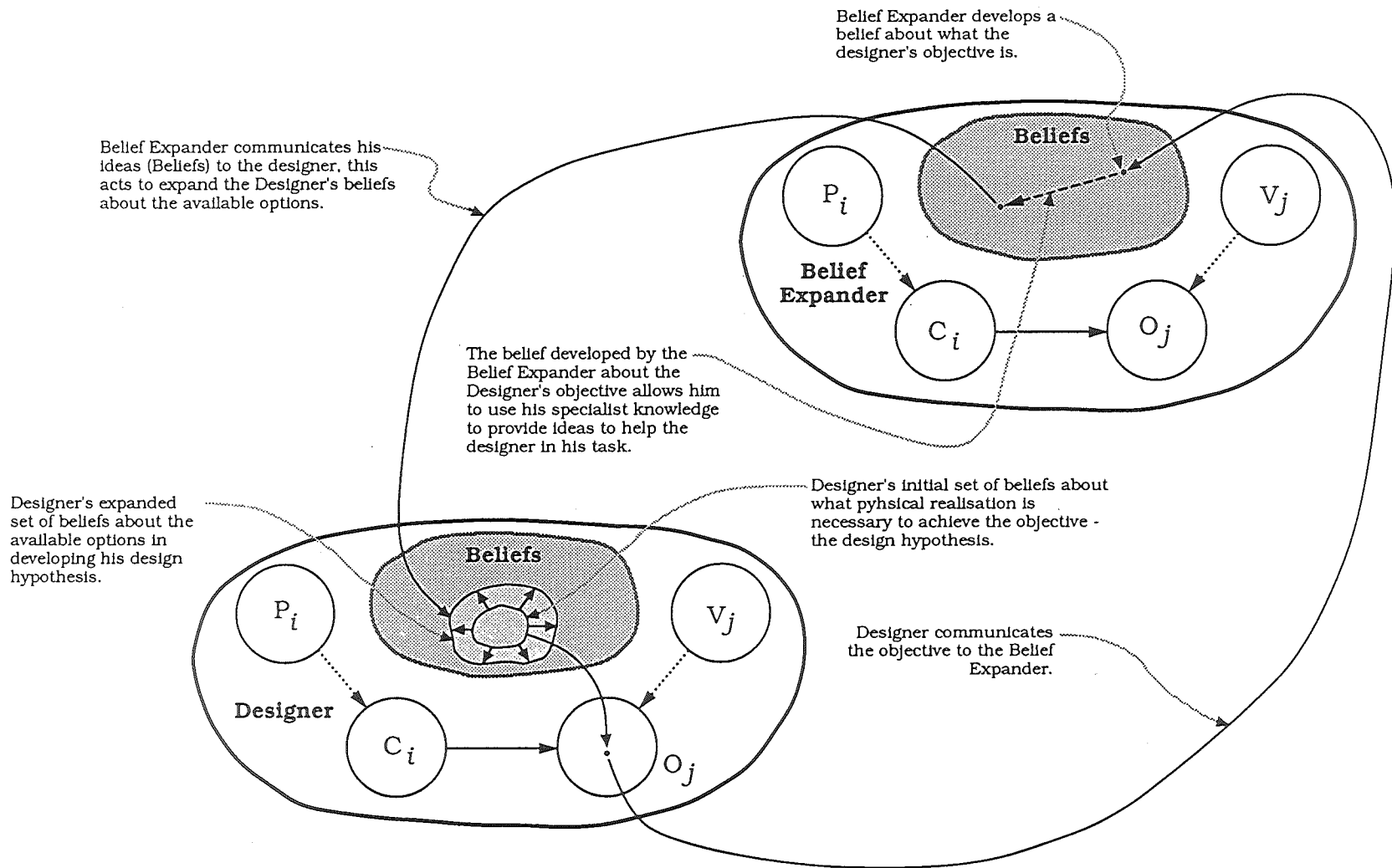
In the relationship between the designer and the functional expert two things must be stressed. Firstly, that although the interactions so far have been dealt with serially, they may in fact, and almost certainly will, occur in parallel. Thus in negotiating the desired/required set of structural and functional properties with the client, the designer is likely to interact with the organisation to clarify his own understanding of what the organisation is capable of. Secondly, and possibly more importantly, the designer is bound by what the functional experts tell him, and cannot go outside their organisational constraints i.e. what they set as the organisations capability, unless he goes to company management to have the abilities of the organisation changed, e.g. the purchase of additional machinery.

The roles so far have been concerned with the integration of the environmental need (the client or client group requirements) with the technical capability of the organisation, the next three interactions are concerned with the designer's design hypothesis, or how he intends to achieve the defined set of structural and functional properties.

#### **4.3.4 The Designer - Belief Expander Interaction**

The role of a Belief Expander is a simple one, he is purely intended to give the designer additional ideas. The designer will have an initial hypothesis about how to achieve a solution to the defined objective, the belief expander acts on this hypothesis to expand the designer's possibilities. Such a role was used very successfully in the development of the *Ford Taurus*, here assembly workers made suggestions that drastically reduced the complexity of certain vehicle components compared to previous *Ford* designs [73]. While the designer must actively seek such information, from people such as assembly workers, technicians and assorted written material (e.g. magazines) he is not bound to incorporate it in his design. The very simple description of the interaction between the Designer and a Belief Expander is shown diagrammatically in figure 4.5.

Figure 4.5 Designer - Belief Expander Interaction



#### 4.3.5 The Designer - Critic Interaction

The *Concise Oxford* dictionary [41] defines a critic to be:

*One who pronounces judgement; censurer; judge of literary or artistic works, esp professional reviewer of books etc.; one skilled in textual criticism.*

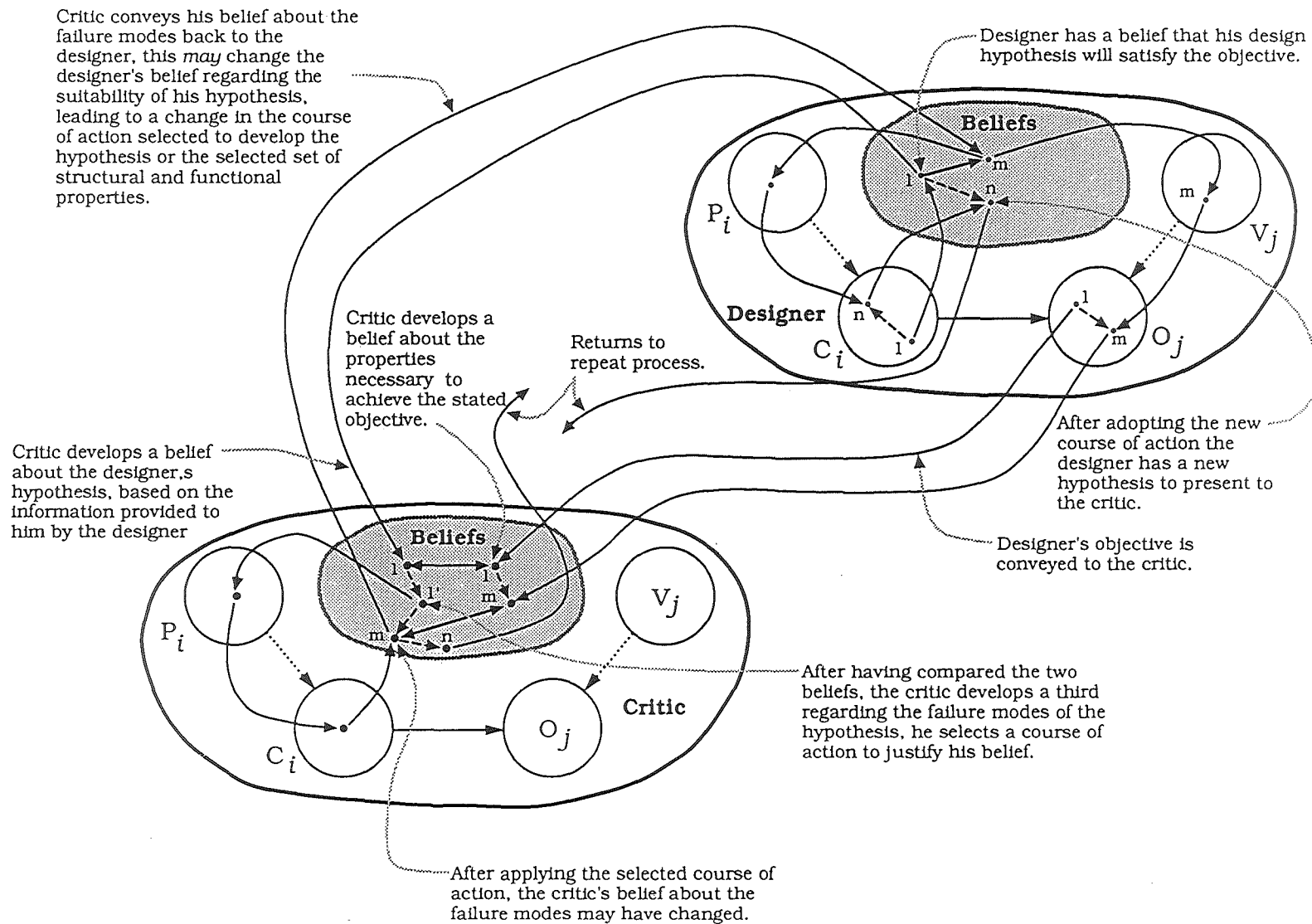
Thus a critic is someone who uses his skill to review and judge the work of another. This is exactly the role of the critic in the Purposeful Design Model and as such is effectively the designer's enemy.

It is essential that critical appraisal of the designer's concepts and hypothesis occurs. If it does not then it is likely that the design will contain design errors. Such errors often result in the recall of the product, for example a motor vehicle. The role of the critic is captured entirely in a quote from Petroski's book *To Engineer is Human* [74], *Success is foreseeing failure*

The task of the critic is to determine all the failure modes of the designer's hypothesis; whether it be, mechanical strength, vibration frequencies or market share. Additionally the critic could be someone like the client, who critiques how well the designer's hypothesis satisfies what he really wants. Or it could be a production worker, who criticises the hypothesis on its ease of manufacture, for example. It is also through the critic role, that functional groups can check for compliance with their previous Designer - Functional Expert. Here the functional groups use their own conceptual space to check the designer's comprehension of their spaces, and thus ensuring all considerations are correctly integrated into the designer's hypothesis. Figure 4.6 shows the Designer - Critic interaction, and clearly indicates the iterative nature of the interaction.



Figure 4.6 Designer - Critic Interaction



The interaction begins with the critic being made aware of the designer's objective, in this way he can develop a belief about the type of solution to be sought - this coming from previous experience. The designer also communicates his belief about the developing hypothesis to the critic. The critic now compares the two beliefs and selects a tool (a course of action) to justify his belief about the designer's hypothesis and thus its validity e.g. the strength is too low to achieve his desired outcome, or the cost of the product is too high to achieve the stated market share requirement.

The critic then conveys his new belief back to the designer, who in turn may modify the selected system of structural and functional properties (possibly after undertaking interactions with the client and the functional experts). Alternatively, the designer may be forced to select an alternative course of action in determining his design hypothesis, such as using sophisticated analysis tools instead of simple calculations when deciding the characteristics of certain components.

The process now repeats until such time when the *modes of failure*, as exposed by the critic, are outside the designer's area of concern e.g. critical speed of crankshaft occurs at an engine speed of 10,000 RPM. Throughout this process, the critic is responsible for developing testing procedures to verify the modes of failure he has illuminated.

Throughout this section the tone of the discussion has suggested that the critic is not the designer, this is in fact the preferred situation. While the designer will criticise his own work, before releasing it to the wider organisation, it is felt that the designer is too intimately involved in the development of the design hypothesis to be totally impartial and thus find **all** the faults that it may contain.

The critic's role is one of the most important in the development process, it is essential for monitoring the integration of the designer's conceptual space, with those who have interacted with him previously e.g. client, functional experts, belief expanders. It

is also essential for eliminating as many design faults as possible, before the release of the resulting hypothesis to the client.<sup>1</sup> The role of the critic cannot be over stressed. While the roles discussed so far are vital to the development of the designer's design hypothesis, the description has been restricted to one level of recursion. The following section will outline the recursive structure of the model and explain how this structure is useful at all levels of the organisation, whether it be concerned with the design of the organisation or the design of a machine component made by that organisation.

#### **4.3.6 The Designer - Sub-Designer Interaction**

Throughout the course of a hypothesis development project many decisions are required to be made, whether it be to design a particular type of sports car, in order to satisfy organisational goals, or whether it be the shape of a component within that car. While these decisions may look essentially unrelated, the truth is that they are fundamentally the same, differing only in the complexity of the issue being dealt with. The same argument was put forward in the previous chapter, there the two situations were linked using the concept of recursion, or invariant pattern. Again the two issues can be related using this concept, thus recursion in the hypothesis development process is integral to the Purposeful Design Model.

The designer is a creator; a creator of systems capable of exhibiting desired structural and functional properties. If the system to be designed is complex, then it may be simplified by regarding it as an assembly of interacting sub-systems [34,35,36], each exhibiting a sub-set of the wider system properties. In turn each sub-system may be sub-divided again, or as many times as is necessary to reach the level of component design. Thus the design of an artefact may be regarded as being recursive, the system of properties at recursive level  $n$  being comprised of the structural and emergent properties of each of the sub-systems,

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<sup>1</sup> In the case of a design hypothesis, the client would view the resulting hypothesis in the form of an artifact. The outcome of a planning hypothesis would be a plan.

recursive level  $n+1$ , plus the emergent properties due to the interactions of the sub-systems, this is illustrated in figure 4.7.

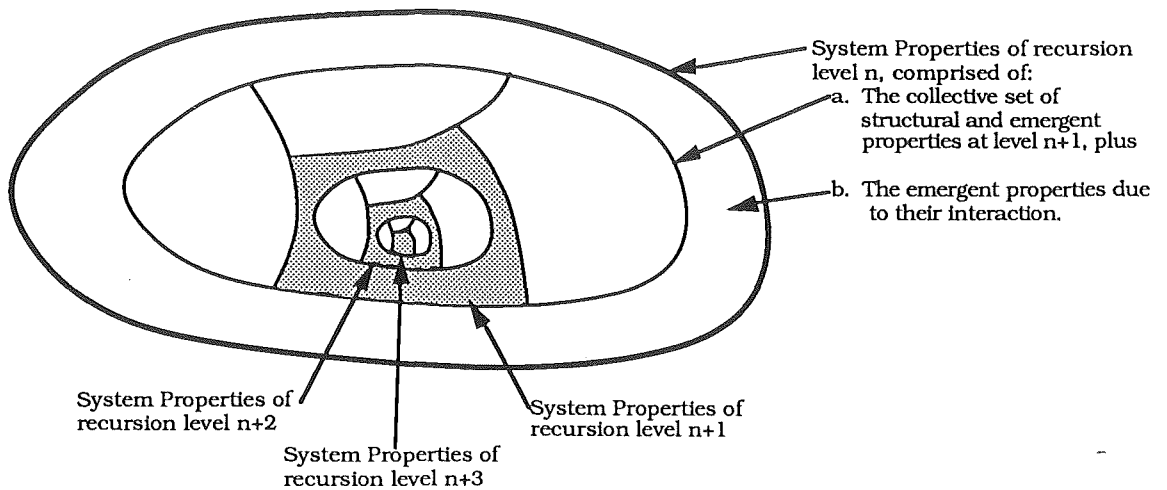


Figure 4.7 The Recursive Nature of Design

While all the activities to be discussed in this chapter, should be linked recursively (to enable integration of the overall system), it is the core development process that links designer's at different levels, that is fundamental to the success of the PDM.

The designer is responsible for integration of the total design at his level of accountability, he must therefore have the complete system in mind at his level of recursion. Thus the design of a new car would require a designer, at the highest level of the development project, to have the entire car in mind. Not detail such as the piston sizes, or the like, but rather the type of system he is looking for e.g. front engine, rear wheel drive, manual gear box, top speed of  $x$ , acceleration of  $y$ , price of  $z$ .

The designer at that level will then divide the task into *lower level* tasks, such as the design of the engine, gearbox, or body, these now becoming the objective of designer's at the next lower level. The task of the designer is then to ensure that the various *recursive dimensions* integrate with one another, and thus achieve the desired objective.

The designer who is given the task of designing the engine, will then undertake conceptual design in the same way the designer *above* him did, negotiating with that designer the set of structural and functional properties to be achieved. In this way the *higher level* designer is a customer to the engine designer. In developing the final set of properties to be achieved, the lower level designer will also have to interact with various functional experts, in exactly the same way as the designer above them had, except now the issues being considered are at a different conceptual level.

The interaction with the functional experts at the higher level will have *set the scene* for the project, and plans will have been developed by the various functional groups regarding their role in the development project. Thus the interaction of lower level designer's with representatives of the functional groups, will result in another set of plans, these will be at a more detailed level but will remain consistent with those made at the higher level. This process repeats at every level of recursion and results in a fully integrated approach to the hypothesis development process. Because the critic's function is performed at each level of recursion, the designer's interpretation of the plans is checked by those who developed them, the result being that integration is more certain. The interplay between the critics at various levels also acts to ensure that organisationally integrated plans result from the development process.

While it is the designer's responsibility to ensure that each of the recursive dimensions established by him integrate correctly, it is essential that the various recursive dimensions interact to ensure their designs are compatible, with the higher level designer mediating any instability that may occur due to persistent differences. Figure 4.8 shows the relationship between the designer and his sub-designers in a two recursive dimension case

The interaction begins with the designer's belief about the properties needed to achieve the desired objective. He then splits it into subsets of properties for the various recursive dimensions. The sub-designers are informed of the designer's overall objective, they each develop a belief, about the set of structural and

functional properties the designer desires/requires for their particular recursive dimension. They compare their two beliefs and develop a set they believe is more appropriate and feed this back to the designer. The designer compares this with his previous belief, and makes a decision that modifies his desired set of sub-structural and functional properties, or his previously held belief about the overall set of structural and functional properties. At each stage the designer is considering the integration of the various lower recursive dimensions. This process continues for  $n$  iterations until agreement is reached on the set of properties to be achieved.

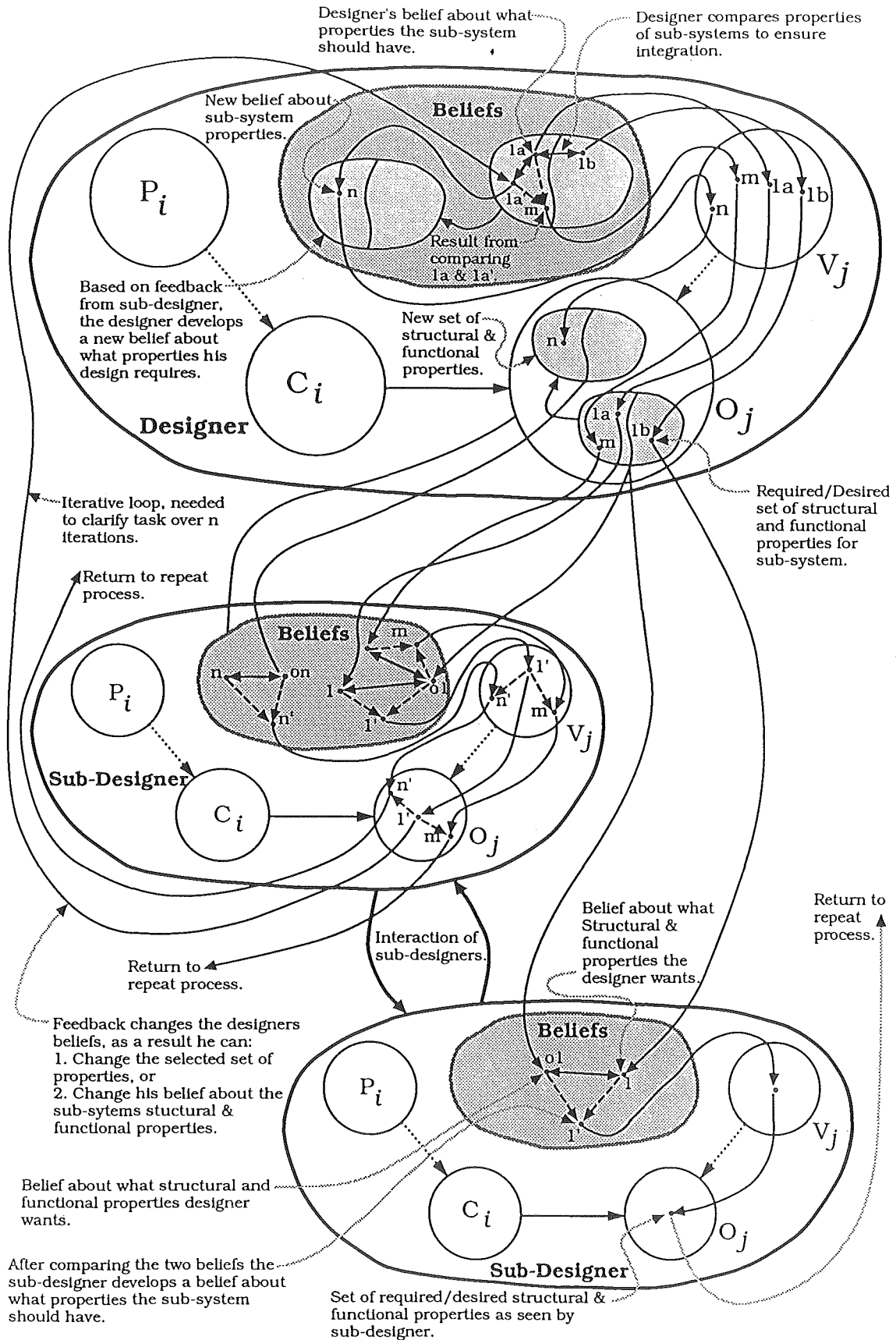


Figure 4.8 Designer - Sub-Designer Interaction

The above discussion talks of the designer working at levels such as the overall concept of a car, or its engine, the levels of recursion, however, continue down to that of component detail design, where such details as surface finishes and tolerances will be decided. The designer at that level being involved in a design process identical to that of the highest level designer, the systemic properties being the only things that change.

The initial ideas of McCallion [72], and supported by Brooks [71], included a person to develop *tricky* ways of doing things. This role is not included in the model developed here, as it is considered that such an individual would simply be acting as a designer at some lower level of recursion.

The ability of one designer to delegate a recursive dimension to another designer, is dependent on whether he believes that individual to be capable of achieving the desired task. Thus the higher level designer has a belief about the type of individual required to perform such a task. If the lower level designer does not have the necessary belief system, to interact meaningfully with the higher level designer, then the two will not be able to integrate their activities adequately. Thus certain individuals will have the correct belief systems (based upon life experiences) to perform design activities at the highest levels of recursion. While others will be restricted to the lowest levels, where their belief systems are appropriate to the decisions being made. It means, therefore, that people should work at the level appropriate to their belief systems, in other words an experienced engineer should not be making decisions about production details that he has little knowledge of: those decisions should be made by a shop-floor worker, within the guide-lines negotiated between the designer and the worker. In the same sense a shop-floor employee should not be commissioned to make design decisions requiring years of technical training.

Throughout the development process the designer is going to be developing and changing his design hypothesis, as he sees new and better ways of achieving his goal. If allowed to act unconstrained the designer could, in theory, continue fine tuning



his solution indefinitely, this being ultimately to the expense of the project. While a designer's continual making of improvements to his hypothesis might enhance the final solution, the extent of the improvements may be too small as to be considered significant by the client. It is therefore necessary to *freeze* the design hypothesis, at a point where it adequately satisfies the objectives of the project.

#### **4.3.7 The Design - Design Hypothesis Freezer Interaction**

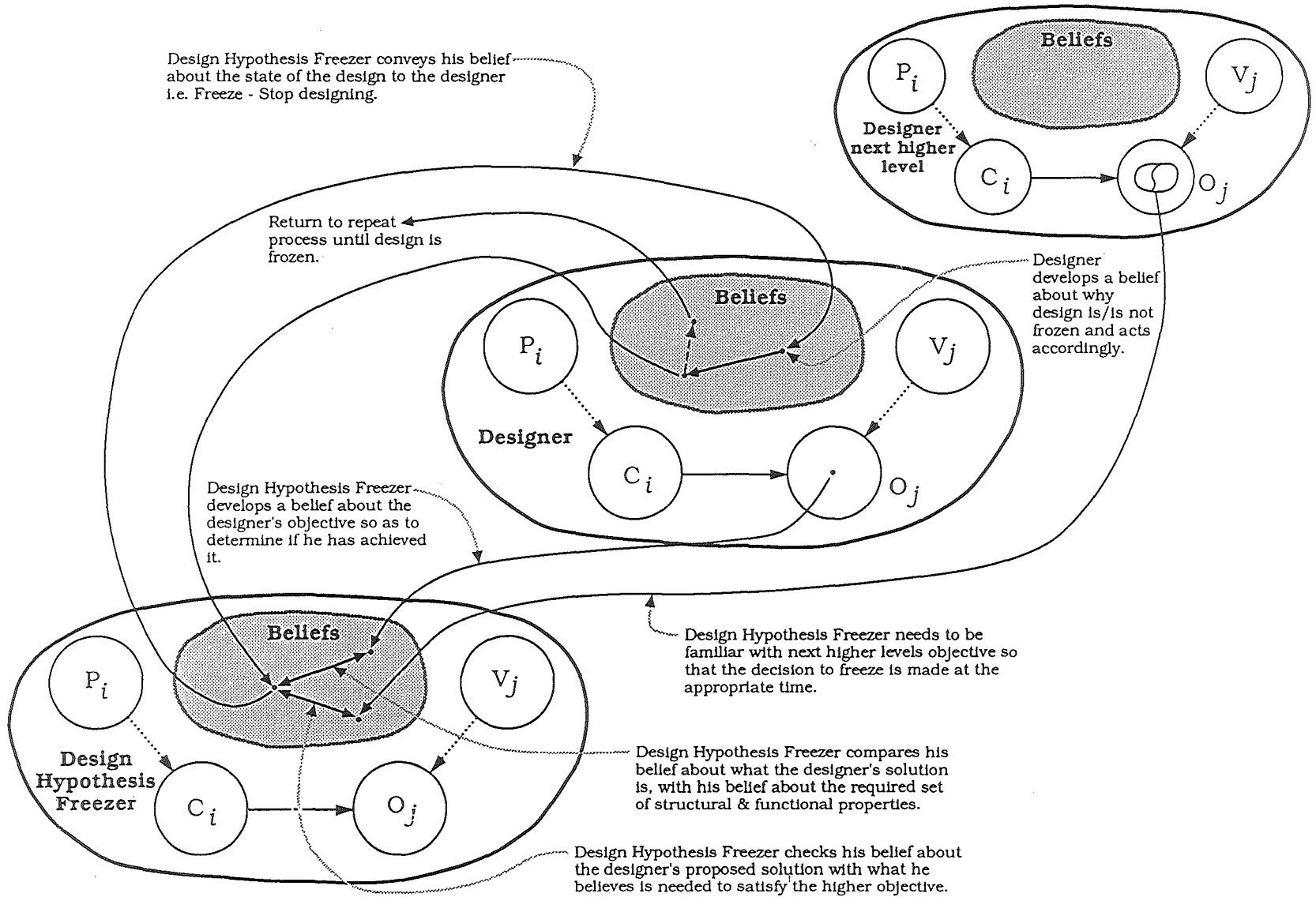
It would be argued by most design engineers, that it is they, and only they, that can decide when a design should be frozen. However, it is also them that have trouble standing back from their work to say *enough is enough, any further change I could make would not add significantly to the overall design*. Sir Henry Royce is a classic example of a designer's inability to stand back from his work. While an exceptional engineer, Royce could always see things to improve, the effect is to delay the release of the product.

The role of the Design Hypothesis Freezer (DHF) is to interact with the designer, comparing his belief about the higher level objective with what the designer has achieved. If he feels the designer has adequately satisfied his goal then he directs the designer to stop any further development.

Because the DHF needs to be familiar with the objectives of the designer at the next higher level of recursion, it is conceivable that it is the designer or co-designer at that higher level who acts in the role of DHF.

Figure 4.9 shows diagrammatically the relationship between the designer, the Design Hypothesis Freezer and the overall objective of the next higher level designer.

Figure 4.9 Designer - Design Hypothesis Freezer Interaction



While all the preceding roles have related to the development and testing of a design hypothesis, nothing has been said about how the output of the process is communicated to the rest of the organisation, or how the administrative requirements of the development process are handled. The following two roles explain these two links with the organisation and beyond.

#### **4.3.8 The Designer - Documentor Interaction**

Developing a workable design hypothesis is one thing, effectively communicating it to others is another. No matter how long a designer spends developing his hypothesis, if he can not communicate it effectively, then his time has been wasted. The role of the documentor is to ensure that effective communication occurs.

The documentor achieves this by translating and amplifying the designer's beliefs into a *language* understandable to other groups of individuals. This takes the form of operation manuals, maintenance manuals and other similar documents. To do this, the documentor is required to develop a belief about the designer's design hypothesis, along with this he must develop a belief about what others will understand. He is then able to generate documentation based on the beliefs of the designer, for the appropriate groups of individuals. Figure 4.10 indicates the interaction process between the designer and the documentor.

The process begins with the documentor developing beliefs about the designer's overall objective and the design hypothesis developed by the designer. If necessary, the documentor seeks additional information from the designer to enable him to carry out his task. The documentor now has an increased probability of choosing to develop a form of communication to convey the designer's hypothesis, and of selecting a particular course of action e.g. a maintenance document is required, so select standard company format sheet for the production of the document. Using his belief about what the receiver of the communication requires, to enable him to act in accordance with the designer's belief e.g. how to maintain the machine, the documentor will amplify the

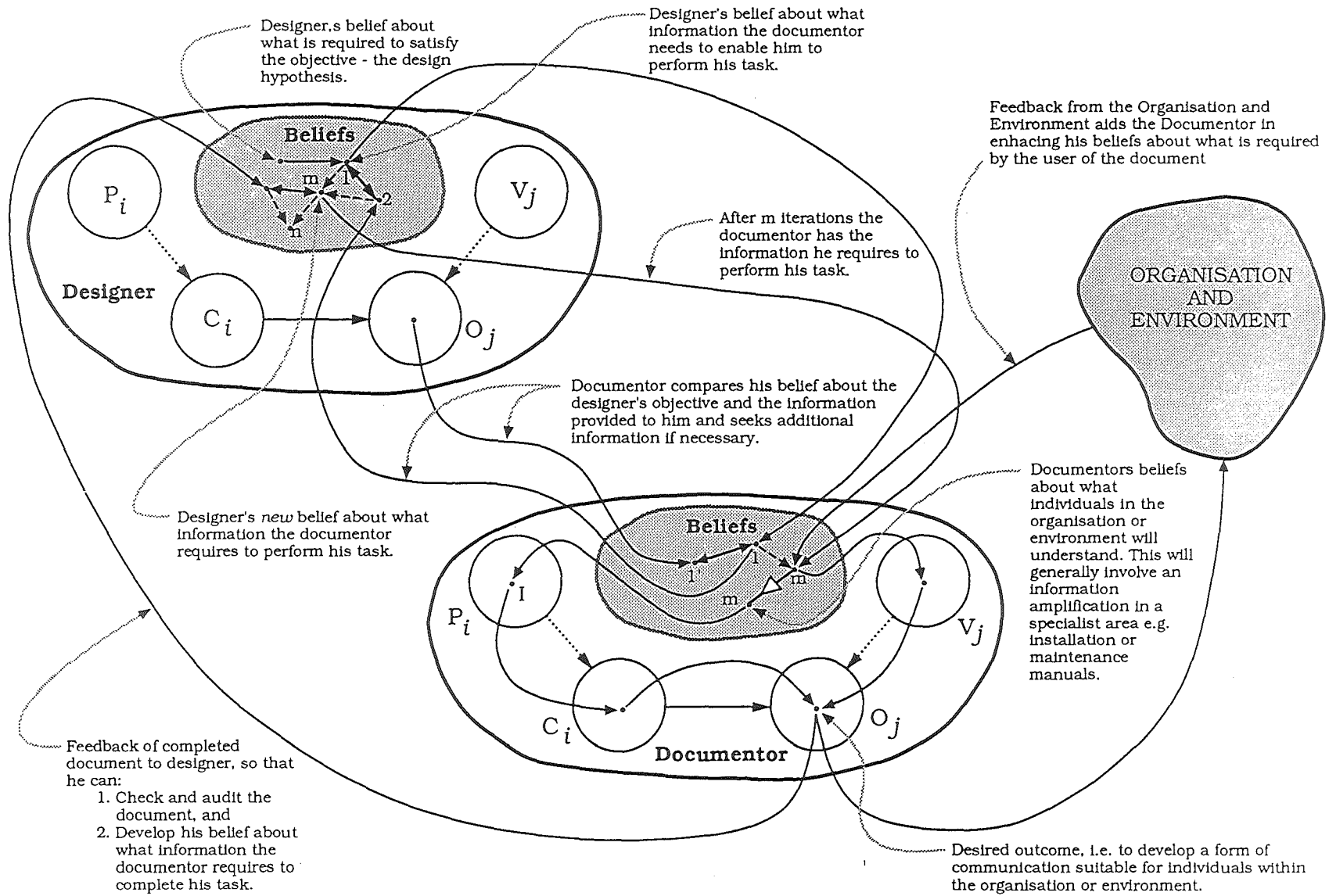
designer's intentions so as to ensure a comprehensive description of the appropriate set of designer's beliefs.

Any documents generated by the documentor will need to be checked for correctness of detail, this can only be done by the designer (or the co-designer), in doing so it also acts to modify the designer's belief about the information requirements of the documentor.

While communication of the designer's hypothesis is central to the documentor's role, he is also required to record, store and retrieve all forms of communication generated during the course of the project. Thus classification and coding of information is integral to the documentor's role, whether it be the classification and coding of generated documents, or of new designs produced as a result of the development process, these documents and designs can later be retrieved and used as belief expanders.

If the role of documentor is performed by an individual other than the designer, then the burden on the designer is reduced significantly. Further burden can be removed by the addition of a professional administrator.

Figure 4.10 Designer - Documentor Interaction



#### 4.3.9 The Designer - Administrator Interaction

As with the documentor, the administrator<sup>2</sup> is a link to the *outside world*, in this case the rest of the organisation. He is someone who can take the high variety communications from the organisation and translate them into lower variety communication for the designer. Conversely he takes the lower variety communication from the designer and amplifies it and puts it into the *language* of the organisation. The administrator must therefore *speak two languages* the *language* of the organisation and the *language* of the designer. Figure 4.11 shows this diagrammatically.

An inflow of information from the organisation is marked with an *I* while a flow from the designer, out to the organisation is marked with an *O*. In the case of the designer communicating with the organisation, the designer develops a belief that a communication needs to take place, this raises his probability of selecting to communicate. Having decided to communicate with the organisation he conveys his belief to the administrator who amplifies it and selects the most appropriate course of action to achieve the outcome of communicating e.g. a company designed form, such as a memo sheet.

In response to the communication the organisation may reply, the administrator receives the reply and filters it for transmission to the designer, selecting what he considers to be the most appropriate course of action to do so e.g. private discussion. The designer receives the information from the administrator, raising his probability of selecting a particular outcome and a course of action to achieve that outcome.

The administrator aims to relieve the designer of as much burden as possible, allowing him to get on with his job of designing. Further to the task of interfacing between the designer and the organisation he coordinates the activities of the designer with the client, critic, belief expander, documentor etc. roles, if these are played by people other than the designer. Thus he establishes the

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<sup>2</sup> Administrator: Manager (of business or public affairs); one capable of organising... [41].

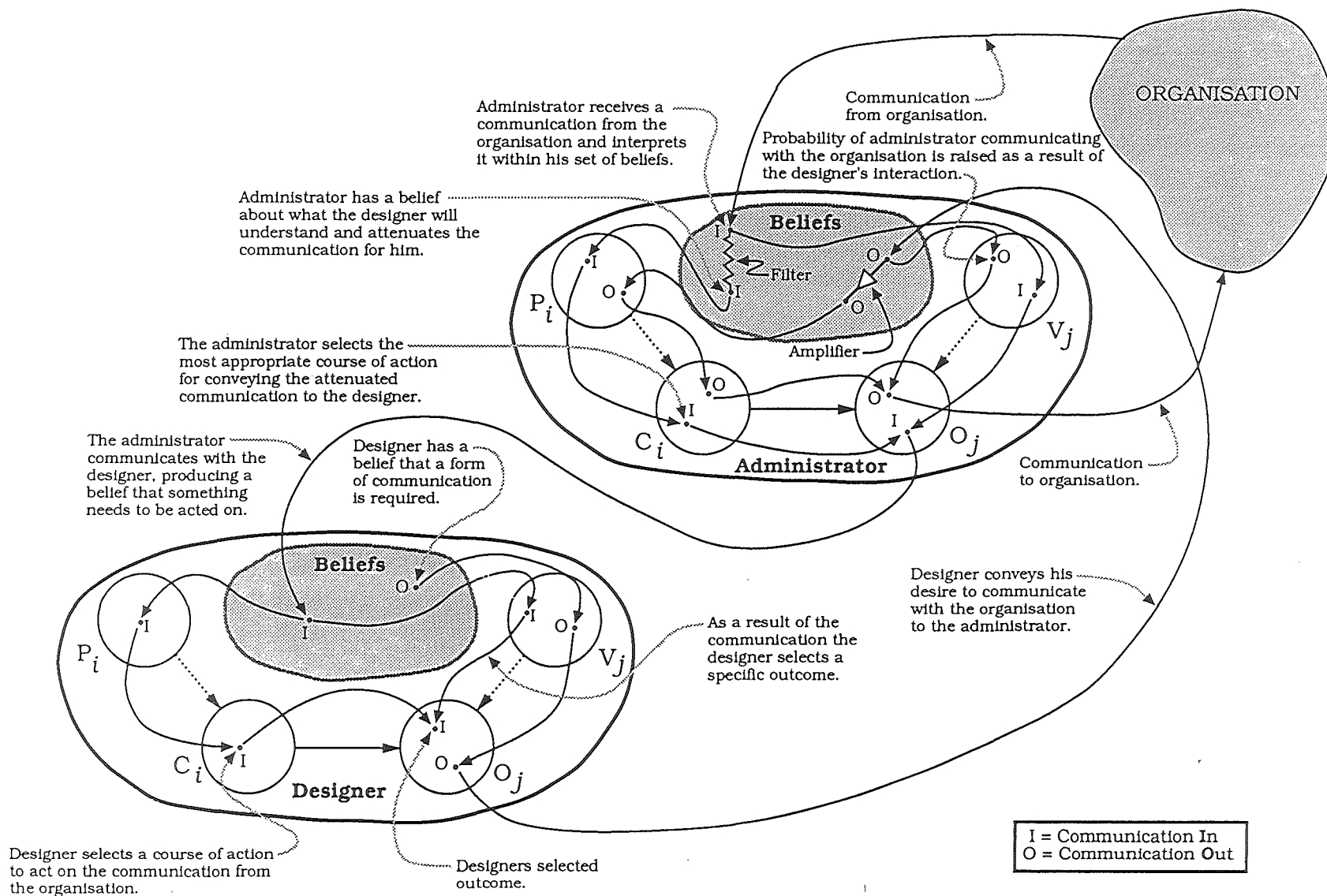
contacts regarding who to talk to about x, y and z, and monitors the effectiveness of the communication process. He must ensure that the communication effectiveness is as high as possible i.e. ensuring its actuality approaches its capability. If actuality is low, the administrator must ascertain what the problem is, and if possible, act to improve it. This he will do from his previous experience or by investigating other similar situations. He may discover, for example, that a designer is having trouble with a sub-designer because the sub-designer's background is inadequate, he must then act to rectify the situation.

Finally the administrator is responsible for taking care of routine matters, for example conditions of employment/contractual arrangements and maintenance of facilities required by those involved in the development of the hypothesis.

Use of the PDM will in general require the interaction of a group of skilled individuals, it has been stated that the administrator is responsible for establishing and monitoring these interactions. Because of this, it is felt that the administrator is the ideal person to be responsible for maintaining the motivation and values of the individuals involved. Through his knowledge of the on going interactions, the administrator will be familiar with the level of motivation of all those involved, he is therefore in a position to try and improve motivation, so that the effectiveness of the interactions can be increased. The administrator's contact with both the organisation and the design *team*, also places him in a position to assess the values of those involved, and if necessary act to bring the *team's* values back in line with those of the organisation. It is the administrator's unique position that makes him so suitable for the job, his relative *neutrality* to all members of the *team*, ensures that the role of motivator and keeper of values can be achieved without antagonism or veiled threats.

If the administrator discovers a problem beyond his capability, for example a difficulty experienced in all projects, or if a team member isolates a *bottle-neck* in his performance, they must call on the last member of the Purposeful Design Model, that person being the Developer.

Figure 4.11 Design - Administrator Interaction





#### 4.3.10 The Team Member - Developer Interaction

The developer is a *tool maker*, he produces or brings *tools* into the organisation that clear company wide *bottle-necks*, and raise the capability of the total system.

Apple computers employ such an individual in their organisation, quoting from Cortes-Comerer [73]:

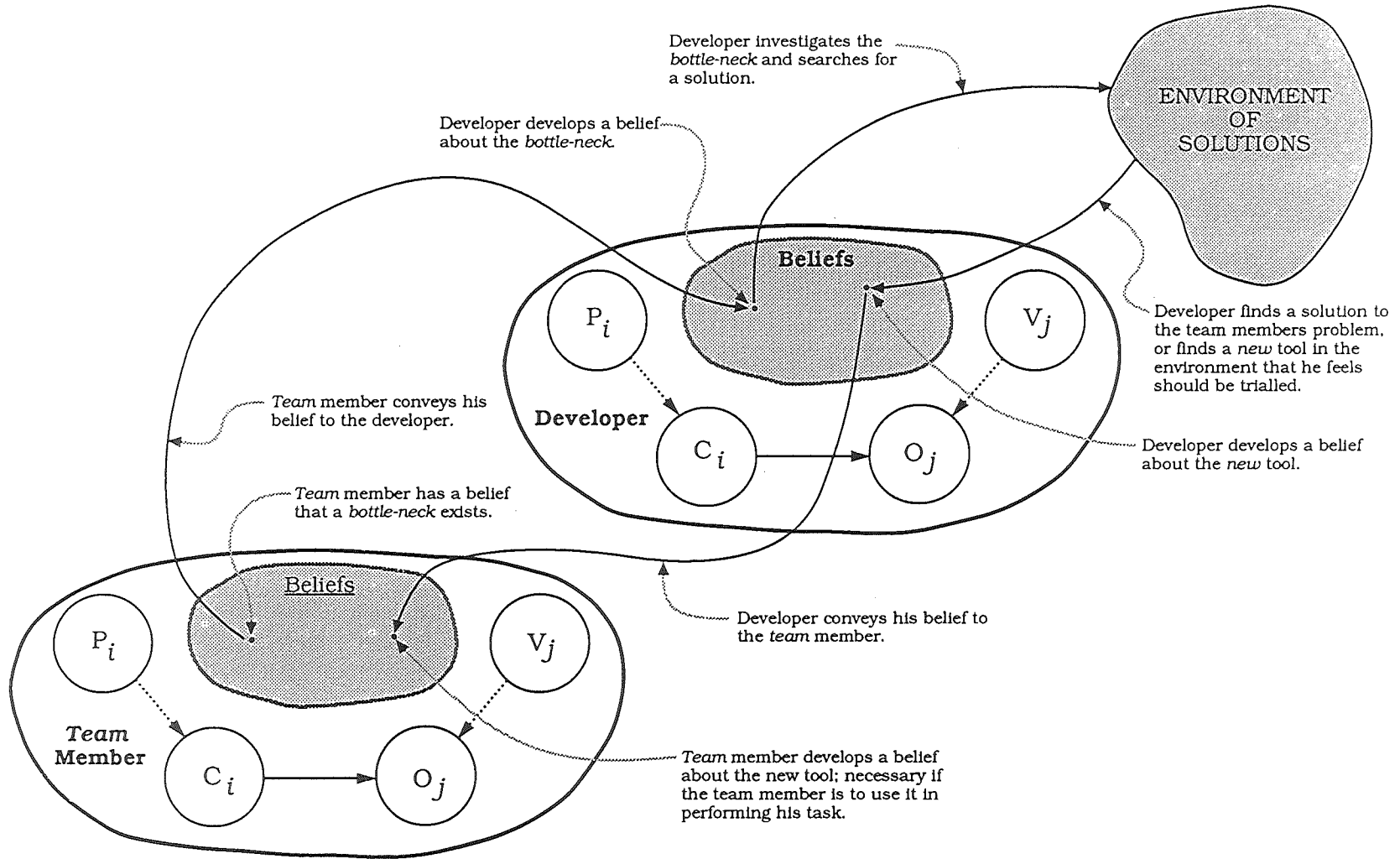
*He can interrupt work on a project for three months to build tools that will make similar projects easier in the future.*

The developer's role can begin at two points, either as a request from a member of the development team, or the discover of new tools either in the environment or invented by himself. An example of the former is the realisation that manual calculation of engine natural frequencies is a bottle neck in the development process. The response from the developer might be to develop a computer system capable of evaluating the frequencies in a fraction of the time. Introduction of *Brainstorming* into the development process would be an example of the developer's role being initiated by a discovery in the environment. The developer may introduce brainstorming on a trial basis to see if it improves the conceptual design capabilities of the organisation. Figure 4.12 outlines the interaction of a team member with the developer.

The diagram shows that if a team member has a belief that a *bottle-neck* exists in the development process, he conveys his belief to the developer who searches for a solution. On finding a solution, or discovering a potentially new tool, the developer interacts with the team member, generating a belief within him that the tool will solve his problem or improve his performance.

The role of the developer is external to the hypothesis development *team*, he must be free to observe the interacting *team* from an outside view point.

Figure 4.12 Team Member - Developer Interaction



Eleven roles exist in the PDM, resulting in ten different types of interaction, some of these roles are central to the development process, while others act to enhance the capability of the system, a sort of line and staff structure. The relationship between the various roles will now be discussed.

#### 4.4 Role Relationships

The designer, co-designer and design hypothesis freezer are central to the development of the design hypothesis. Roles such as the belief expander, functional experts, critics and the client feed into the designer to enhance his hypothesis developing capability, while the administrator and the documentor provide the links to the organisation and environment. Figure 4.13 represents the role relationships diagrammatically.

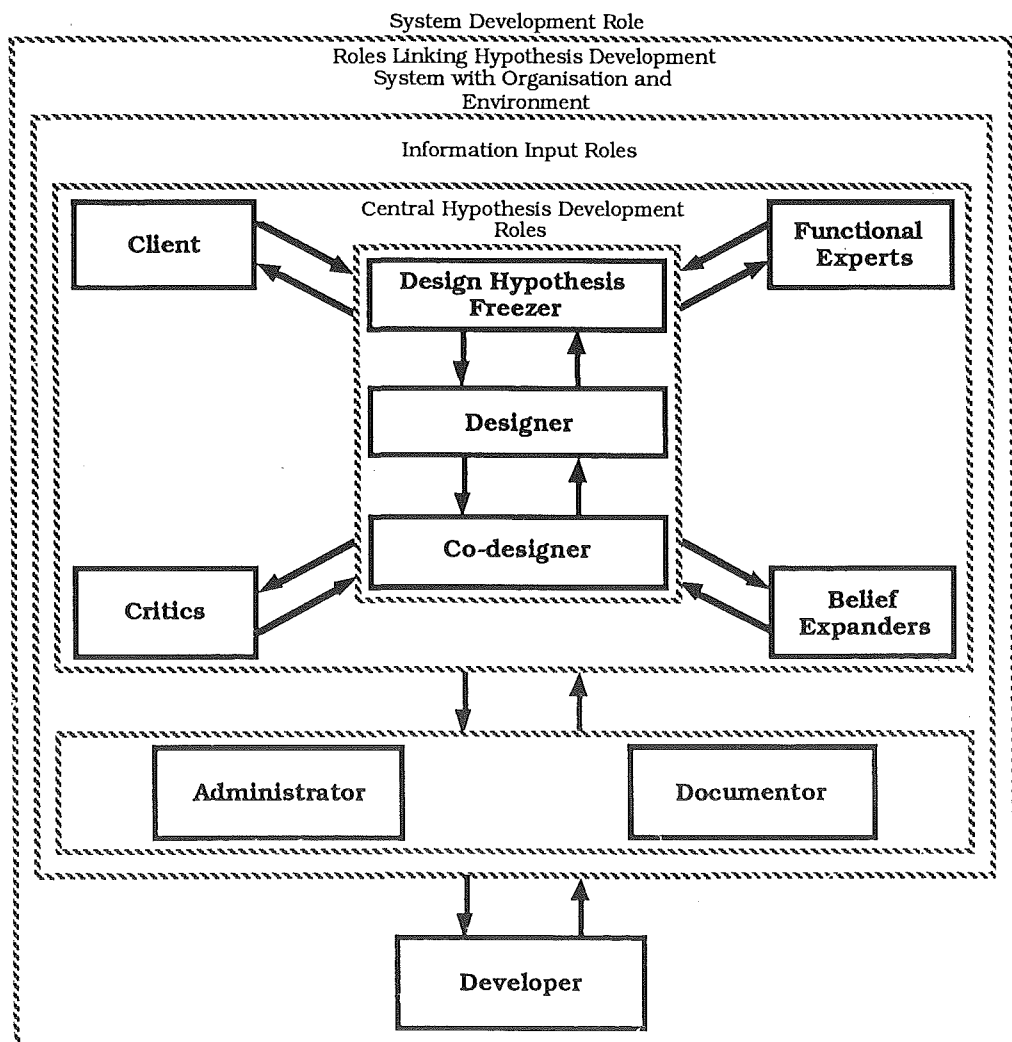


Figure 4.13 Role Relationships

At times a *team* or *group* has been referred to, however, this is a notional concept. The roles within the PDM are exactly that and may be performed by a single individual, or a large group of interacting individuals. Ideally at least some of the roles should be performed by people other than the designer, for example the co-designer and the critics.

It is possible to consider the model as the tool for managing a team, yet it is likely that some roles may be better served by being external to any dedicated group of individuals, for example the critics. While in large projects it is common to assemble a team, it is not necessary, except possibly in the case of the central roles. All other roles being performed by interactions with the appropriate organisational groups, in a type of client vendor relationship.

The Purposeful Design Model is very different to anything else currently being reported in the literature. The following chapter will outline how the PDM places existing design methods in a wider framework. It will also outline a control system for the interaction model to be used in resolving any instabilities that may occur.

## CHAPTER 5

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### THE PDM IN A WIDER CONTEXT

#### 5.1 Introduction

The previous chapter introduced the *Purposeful Design Model* and outlined the roles necessary to achieve an integrated approach to hypothesis development. It also outlined the recursive nature of the model and how this enabled a complex system of interactions to be unravelled.

This chapter will show how the *Purposeful Design Model* places existing design methods in a larger framework. It will also discuss how it can be used to achieve a high degree of organisational integration, through the interaction of parallel development *teams*. Finally the chapter will outline a control system as appropriate to the PDM and how this could be computerised to produce computer driven hypothesis development software.

#### 5.2 Existing Design Methods in the Larger Framework of the PDM

For the PDM to be of any real value it must be able to place any existing, or new hypothesis development methods within its framework. This section will take a subset of the current design methods and discuss them in terms of the purposeful design model.

##### 5.2.1 Systematic Design Methods

The systematic approach to the design process has in general come from German researchers, such as Matousek [24] in the early 1960's, Pahl and Beitz [28] in the 70's and Hubka [29] in the 80's. The systematic approach has become so fundamental to German design that VDI, the German Standards Association, has developed a *Systematic Approach to the Design of Technical Systems and*

Products [31]. Figure 5.1 is a reproduction from that guide - VDI 2221.

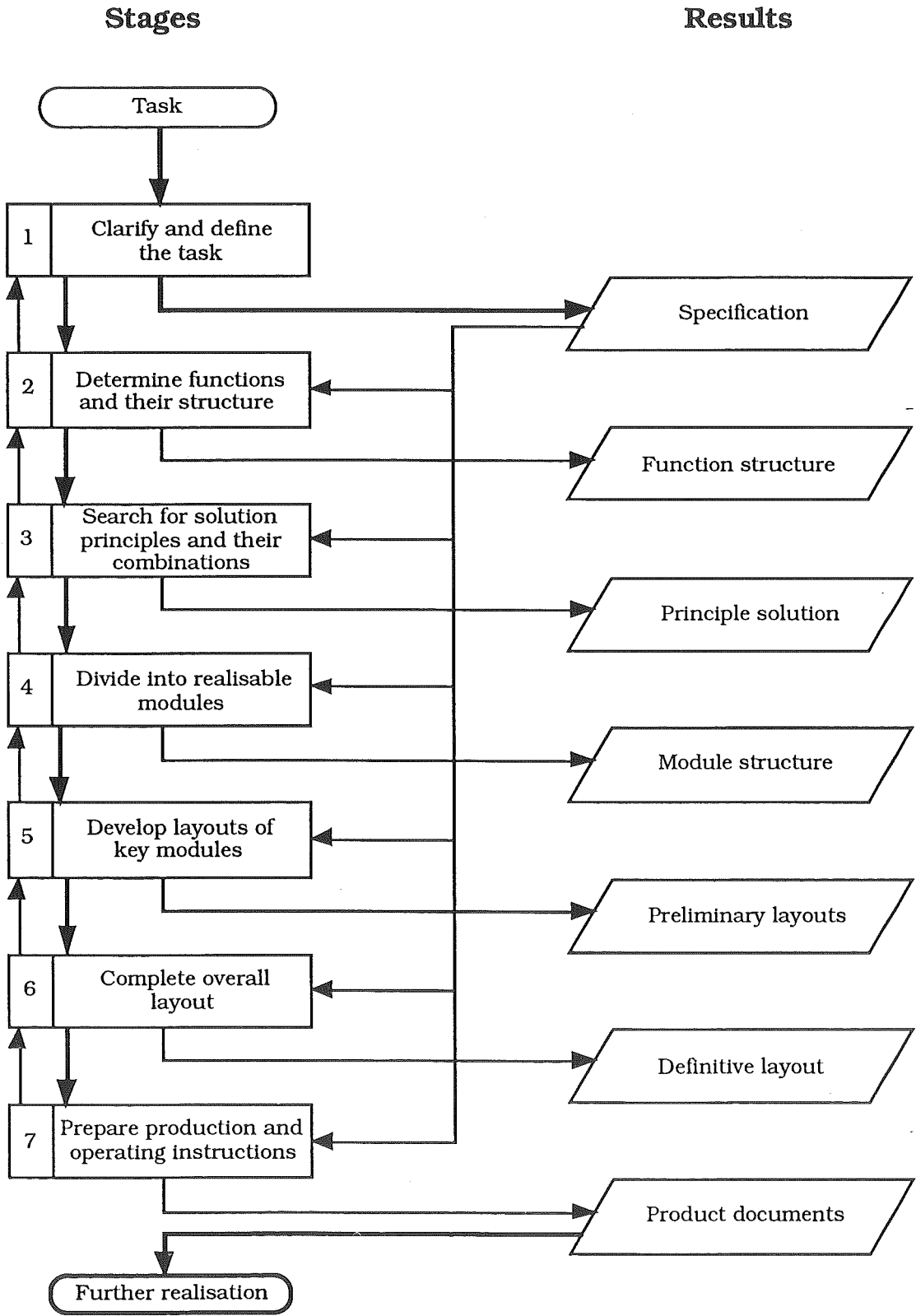


Figure 5.1 General Approach to Design [From 31]

Each stage in the approach describes a clear set of activities that must be performed if the approach is to be successful. The first stage, *clarify and define Task*, is said to include:

*collecting all the information available and discovering where there are gaps; checking and supplementing external requirements; adding specific company requirements; and defining and structuring the task from the point of view of the designer's.*

The output from the first stage is the *specification or requirements list*.

In the framework of the PDM this activity is clearly performed by the designer, through his interactions with the client and various functional experts. However, unlike the VDI 2221 description, which implies this occurs only at the outset of the project with all detail being specified at that point, the PDM allows, and in fact encourages, the development of the client's specification at every level of the model. While the top level of recursion would certainly obtain most of the necessary information from the client, each recursive level would add to this with additional detail appropriate to their level of interest. The same is true of *specific company requirements*, through the interaction of the designer and the functional experts.

The second stage in the German guide is to *Determine functions and their structures*:

*First the overall function and then the most important **sub-functions** (main functions) to be fulfilled by the product or system being designed. The classification and combination of these sub-functions into **structures** forms a basis for the search for solutions for the overall product or function.*

Within the framework of the PDM this relates to the highest level designer's search for the overall conceptual design, this he achieves by considering the overall function of the system, and those of its major sub-systems.

Stage three is where a search for solution principles and their combinations is made.

The result of the search:

*is a **principle solution** which represents the best combination of physical effects and preliminary embodiment features to fulfil the function structure. It may be documented as a sketch, a diagram, a circuit or even a description.*

This stage represents the search for hypotheses, relating to the structural courses of action necessary to provide the functions of stage two, by the designer, in the PDM this role is supported by the interaction with belief expanders. While again VDI 2221 describes the activity as occurring in one step; in the PDM it is something that would occur at every level of recursion.

*Division into realisable modules* is the fourth stage of the VDI guide here:

*the principle solution is divided into **realisable modules**, before starting the complex and time-consuming process of defining these modules in more concrete terms.*

The fourth stage of VDI 2221 relates to the breakdown of the design problem into a number of recursive dimensions, these representing the *realisable modules* that integrate to produce the complete system, e.g. if a car was the complete system, its *realisable modules* may be; the engine, transmission, body etc.

The fifth stage is where the designer's hypothesis is developed more fully, VDI states it as being where you *Develop layouts of key modules*, where the:

*Level of refinement of the geometry, materials and other details should only be pursued as far as to allow the optimum design to be selected.*

This stage results in the overall or general structural design, the leading structural properties being determined (e.g. maximum or minimum dimensions), consistent with the functions required and the design constraints. Within the framework of the PDM this



relates to design activity at the intermediate levels of recursion, here the designer integrates the more detailed system of structural and functional properties (appropriate to his level of recursion), with the more specific requirements of the organisation.

*Complete overall layout* is the concern of the sixth stage of the German guide:

*the preliminary layouts of the modules are completed by the addition of further detailed information about the assemblies and components previously not included, and by the combination of all assemblies and components ... This stage results in a **definitive layout** containing all the essential configuration information for the realisation of the product.*

This represents the activity at lower levels of recursion, where the designer, through the interaction with appropriate critics and experts, clearly defines the *final* form of the hypothesis i.e. detailed structural design, at this stage all the final structural properties that affect the function of the artifact are determined e.g. dimensions, tolerances, surface finishes. Any details remaining to be defined will not affect the function of the artifact, only the ease with which it is manufactured or assembled for example i.e. the application of *design for* criteria (see section 5.2.2). Stage seven is where this occurs, this is where VDI say you *Prepare production and operating instructions*.

*The result of this stage is a set of **product documents**, in the form of detail and assembly drawings; parts lists; and production, assembly, testing, transport and operating instructions.*

The lowest level of recursion, within the PDM, is where final drafting will occur and details necessary for the production of the individual components decided. The production of documentation is the role of the documentor within the PDM, but whereas the systematic approach has all the documentation being developed at the end, the PDM allows for them to be developed in a recursive manner, with each level providing more detail, within the scope set by the higher level.

The mapping from the *Systematic Approach* onto that of the PDM, shows that indeed the PDM is capable of providing a framework in which to interpret other design methods.

One last comment should be made, that is that the *Systematic Approach* essentially develops through the stages of specification, conceptual design, embodiment design and finally to detailed design. In general the meaning associated with these various stages is consistent with a design moving from the highest levels of the PDM to the lowest. However, unlike the systematic approach the PDM allows for these activities to be performed at all levels within the hypothesis development system.

### 5.2.2 Design Fors

Earlier in this thesis, it was stated that such tools as *Design for Producibility/Manufacturability* [18,19,20], and *Design for Assembly* [21,22] provide a set of principles and/or procedures for the designer to follow when determining the structure of his design. It was further stated that when faced with several *design fors*, the designer may select an inappropriate course of action from the company wide perspective. Lastly it was said that *design fors* concentrated only on the design decisions at the lowest levels of recursion of the organisation's activities.

The PDM allows one to see why these statements were made, firstly considering the final one. Because *design fors* provide the designer with details on what to do, to ensure that artifacts are easier to produce or assemble, they concentrate on manufacturing details rather than system concept details. As a result, only the lowest levels of recursion are affected, through directions regarding such things as tolerances and surface finishes, the higher levels remaining free to continue as they will. The second issue of conflicting *design fors*, represents the difficulty an individual may have in compromising one *design for* for another. Hence a designer may successfully compromise *design for manufacture* and *design for assembly* requirements, yet at the same time push the cost of the component to an unacceptable level, and thus failing to satisfy the *Design for Cost* requirements.

The PDM is a total *design for* model, and is fully integrated from top to bottom; ensuring that the scope of the design decisions are beneficial to all levels of the organisation, as well as ensuring that all design trade-offs are done to minimise the adverse effects to the enterprise. This is achieved initially by incorporating the functional experts into the hypothesis development process at every level of recursion, in this way the designer develops a well integrated design hypothesis. Then to check the quality of the hypothesis, the functional experts become critics, checking to find fault with the designer's proposed solution. Thus a production critic at the highest level would be checking for such things as process capability or the need for technically advanced equipment, while at the lowest levels he would be concerned with details such as tolerances and surface finishes.

The advantage in this system can be seen by looking at a simple example. If a car manufacturer was to design a new high performance engine, then the production critic at the highest levels could tell the designer, at that level, that the existing equipment is not capable of achieving the tolerances necessary for such an engine. The designer is then faced with changing his hypothesis, or going to the organisation's management for new factory equipment. If the designer had been allowed to continue without such information from production, until the final stages of the design process, then considerable time and money would have been wasted, requiring either a redesign or an emergency order for new equipment, the overall effect being to delay the production of the product and a subsequent late release to market.

### 5.2.3 Design by Features

In an attempt to integrate more closely the activities of design and production, researchers have developed a design procedure around the concept of features. A feature being defined as *a region of interest on the surface of a part* [75], such as a hole, slot, pocket or fillet. From this research two main areas have developed. The first is concerned with *recognising* the features once the artifact is designed, using a computer based expert system to develop a description of the part in terms of the described features. This

research field is known as *Feature Recognition* [75,76]. The second is called *Design by Features* [75,77], and is exactly as its name suggests. While the designer is designing he selects features from a database, and places them where appropriate in his design. Throughout the process the designer interacts with the computer to define such things as size, required tolerances and often its function. In this way the designer's intent can be captured (this is not the case with feature recognition). What ever the method used, and both are still in their infancy, the results are used to aid in the development of the production plan.

While such research does offer potential gains in links between design and production, in terms of the PDM the links are only at the level of component design. As a consequence any gain will still be of limited benefit to the overall hypothesis development process, and the organisation it serves.

#### **5.2.4 Integrated Product Development**

*Integrated Product Development is an approach to product development whose aim is to create the proper interactions between the separate activities within the company, resulting from all the employees knowing the aims, roles, methods and tools of integration [27].*

It is a process where functional groups interact and work in parallel to achieve the desired goal of producing a new product. The goals that it sets for itself are identical to those of the purposeful design model. However, apart from specifying certain activities to be performed, and structures to be adopted, the organisation of the Integrated Product Development approach does not guarantee that integration at the important level of the individual occurs; it does not necessarily result in one individual's conceptual space mapping on to another.

Integrated product development relies on parallel activity in the different functional groups, such as marketing and production, the Purposeful Design Model, by virtue of its structure, also encourages

such a parallel development, this will be further discussed in section 5.3.

### **5.2.5 The Concept of Dispositions**

Dispositions is the concept of planning or preparation [41], Myrup Andreassen has taken this concept and incorporated it into his *Integrated Product Development* method [23]. Here representatives of the various functional groups sit down together and plan for a new product, these plans aim to integrate and coordinate the activities of the organisation during the product development process. Because the plans are drawn up by senior representatives of the various functional groups, it means that the resulting plans span the entire organisation, in this way conceptual design decisions incorporate the concerns of all, as do those made when detailed designing takes place. It also means that each functional group can prepare in time for the eventual manufacture and release of the product. Design iterations should also be reduced, since the concerns of those involved will be incorporated from the beginning, and not as a result of continual redesign, as in the case of traditional serial product development.

The idea of planning for an integrated and coordinated approach to the development of a new product, fits well within the structure and methodology of the PDM. This will be explained in section 5.3.

The Purposeful Design Model provides a description of the necessary and sufficient roles and interactions to ensure that effective hypothesis development takes place. Many tools exist for improving the process of design, or its integration with production and the overall organisation, this section has aimed to show how the role of those tools can be explained through the architecture of the Purposeful Design Model.

## **5.3 Parallel Teams and Integrated Planning**

While the Purposeful Design Model is intended for developing and integrated design hypotheses, its applicability may go beyond

design into any situation requiring the development of a hypothesis, i.e. problem solving situations. Therefore the PDM would be applicable to any System Four activity (Beer's VSM), such as marketing, finance, production, as well as design.

Thus each group could operate hypothesis development teams using representatives from the other groups as functional experts and critics. For example, if the marketing function identifies a need in the environment for a new product, then they would establish a *team* to work out the marketing details of such a product. This, as with design, would require an overall concept with detail being added as recursive levels emerge. Marketing would then become designs *client*, as well as being a functional expert and critic at each level of the design hypothesis development system. Design would in turn become productions *client*, with designers also acting as functional experts and critics to the design and planning of the necessary production system. Likewise production would be used as functional experts and critics at each of the design levels of recursion. The intended arrangement is shown in figure 5.2 for three functional groups.

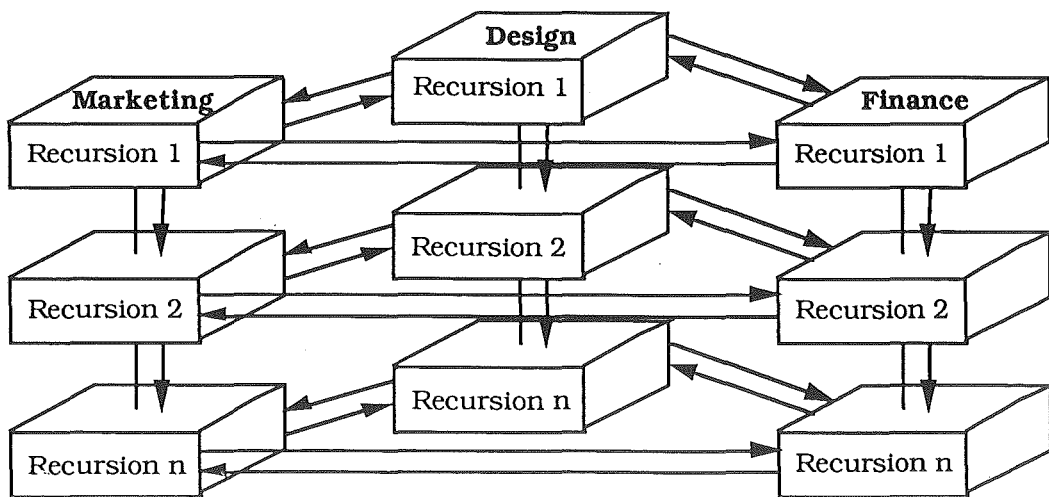


Figure 5.2 Organisational Integration through Integrated Hypothesis development

By having such a structure none of the structural groups will be surprised by unexpected announcements by the other groups. Thus allowing parallel hypothesis development to occur in each of the functions. It also allows for a company wide integrated

approach to be taken, for integrating and coordinating the interactions of the various functional groups. Additionally, due to the recursive nature of the integrated plans, plans made at the upper levels are likely to remain intact even if circumstances change, whereas those made at lower levels can be continually changing. Thus ensuring that the hypothesis always reflects the requirements of the environment, yet remaining within the guidelines set at the higher levels. This ability is consistent with Beer's concept of a *continuous planning process* [46] whereby plans are vetoed as circumstances change, and new ones are made to replace them. This ability of the model adds weight to its usefulness as a System Four integrating tool.

The parallel structure discussed above, and the process of making integrating and coordinating plans means that the PDM is consistent with the work on *Integrated Product Development* (section 5.2.4) and the *Concept of Dispositions* (section 5.2.5).

Due to the interactions necessary for the development of an integrated hypothesis, it is inevitable that from time to time disagreement will occur, this representing an instability in the system. The following section will outline a possible control system for the various interactions to ensure that the instability can be resolved.

#### **5.4 A Control System for the PDM**

When two or more purposeful individuals interact the opportunity for disagreement is ever present, because the PDM relies on the interaction of a group of *experts* the chances for disagreement over decisions made is very real. While the designer, at each level of recursion, is ultimately responsible for the decisions made and the necessary trade-offs to achieve the selected objective, it is likely that from time to time the designer may select the *wrong* variables to concentrate on, while deciding on those necessary trade-offs. The result of such a situation is likely to manifest itself through an unusually high number of iterations between the designer and his critics, although it is not only the hypothesis

development roles that might lead to instability. Interaction with the Design Hypothesis Freezer is another very likely source of conflict, with either the designer demanding the design should be unfrozen, to allow for further development, or demanding it should be frozen due to it being completed.

To ensure that the hypothesis development process continues at maximum pace, while ensuring the hypothesis is sound, some sort of *closure* is required to make sure instability does not destroy the total system. This closure can only be provided by someone with a wider view of what the development process is about, thus in Beer's terminology, it can only be provided by someone who *speaks the meta-language* [44]. Instabilities at any recursive level can only be solved by a higher recursive level, preferably the next higher one. However, if in turn each higher recursive level is unable to solve the instability, closure must be provided by the organisations System Five.

There are a total of ten types of interactions in the PDM, some of these will produce instabilities from time to time, while others will not. Additionally, however, the direct interaction of roles such as critic-critic or sub-designer-sub-designer may also lead to instability at any particular level of recursion.

The preferable situation is that no instabilities ever occur, however this is somewhat utopian. It is therefore desirable that any instability can be resolved within the recursive level in which it occurs. If however a solution cannot be found it must be referred to the next higher level, firstly by being dealt with by the levels co-designer (it is the aim of this model to relieve the designer of burden where ever and when ever possible), and if a resolution to the conflict can still not be achieved the designer at that level must become involved. If the conflict still remains unresolved the problem will need to be passed to the next higher level of recursion, where it will first be dealt with by the co-designer and then the designer before being passed to the next level if still unresolved, and so on until a resolution to the conflict is achieved. The various interactions and the possible reasons for instabilities will now be discussed.



#### 5.4.1 Designer - Client Interaction

The client is the reason for initiating the hypothesis development process in the first place, it is his requirements that are to be satisfied, therefore no instability should occur in the interaction with him. The only decisions that need to be made regarding the client are whether to accept him as a client and whether the organisation has the capability to satisfy his requirements, neither of which should result in instability between the designer and the client. While this remains true in theory, it is seldom the case, with conflict occurring if the client is dissatisfied with the outcome of the development process, however, disputes of this type are external to the hypothesis development system, and will therefore not be dealt with here.

#### 5.4.2 Critic - Critic Interaction

The control system necessary to resolve instabilities occurring in this interaction is *more complex* than for any of the other interactions, therefore it will be dealt with first.

Critics interact at any level of recursion, aiming to find a mutually acceptable compromise, this can be considered as two or more sub-systems acting as self-vetoing homeostats [78] trying to find stable states. An example of the types of compromises that may need to be made may include such problems as the production department wanting the design in terms of modules, while the product stylist wants no modules (in effect trading one *design for* for another). Figure 5.3 shows the complexity of a system of interacting critics.

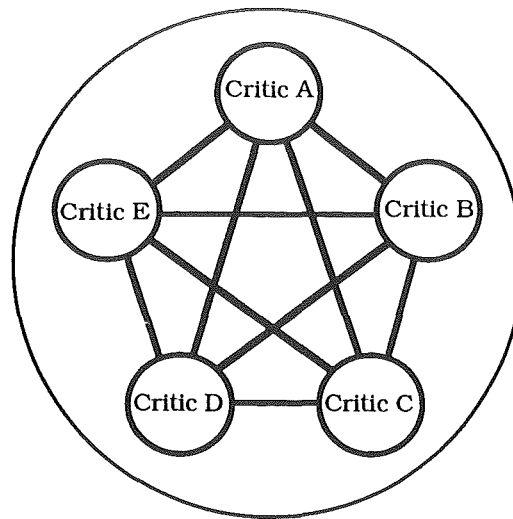


Figure 5.3 A System of Interacting Critics

If the critics are unable to resolve the problem, then after  $x$  iterations or a period of time  $t$  the designer at that level must act to resolve the conflict, thus ensuring his hypothesis development continues unimpeded.

Figure 5.4 shows diagrammatically the type of control system necessary for instabilities in the critic-critic interaction.

It shows how Critic A and Critic B interact to try and achieve a mutually acceptable solution. After a period of time or a number of interactions the designer at their level becomes involved; after all the integration of the solution at his level is his ultimate responsibility. If the designer at level  $n$  is unable to resolve the problem the co-designer at level  $n-1$  becomes involved; via the critics at that level he attempts to resolve the problem. There is also an interaction between the critics at the higher level (this is not shown in figure 5.4, only implied). If the co-designer is unsuccessful then the designer must become involved (same reason as for designer at level  $n$ ), again interacting with the higher level critics. The process continues for as many recursive levels as necessary for the problem to be resolved. Ultimate closure being provided by the System Five of the organisation and/or the client.

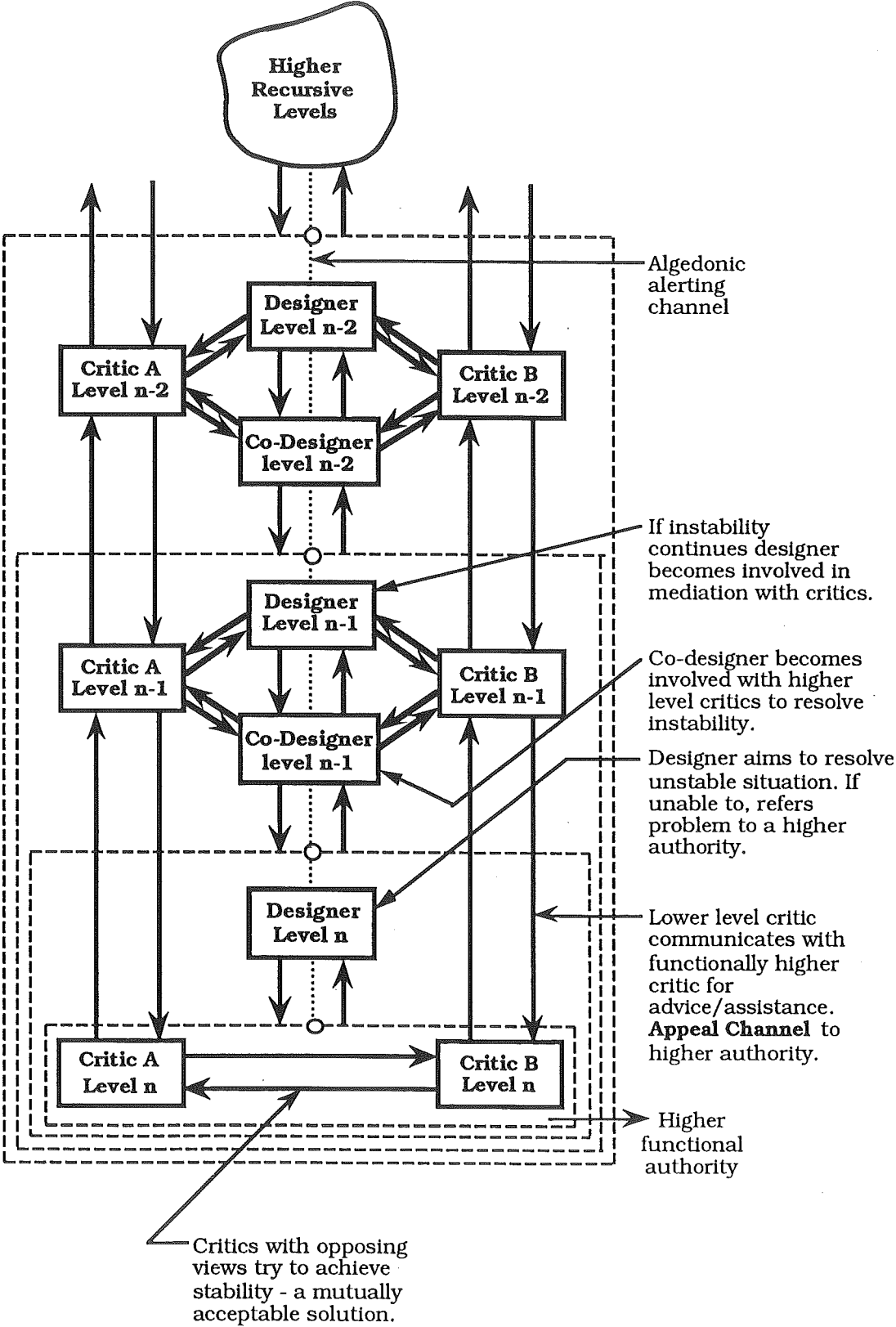


Figure 5.4 Control system for Critic - Critic interaction

Additional to the recursion by recursion interactions to solve the problem, there is an *algedonic*<sup>1</sup> alerting channel, this acts to *tell* the higher levels that a problem exists or that things are going well, this might be achieved using the *Management by Walking Around* technique [79].

Instabilities in other interactions are *less* complex than the one just described, therefore, all remaining control systems will be a special case of the one just put forward.

### 5.4.3 Designer - Critic Interaction

In this interaction the designer and a particular critic cannot resolve their differences, such as in the case where a critic contends the designer's hypothesis is flawed within the scope of the project, and the designer maintains its modes of failure fall outside his area of concern.

Figure 5.5 is the control system appropriate to this interaction.

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<sup>1</sup> Algedonic comes from Greek, meaning *pleasure* or *pain*.

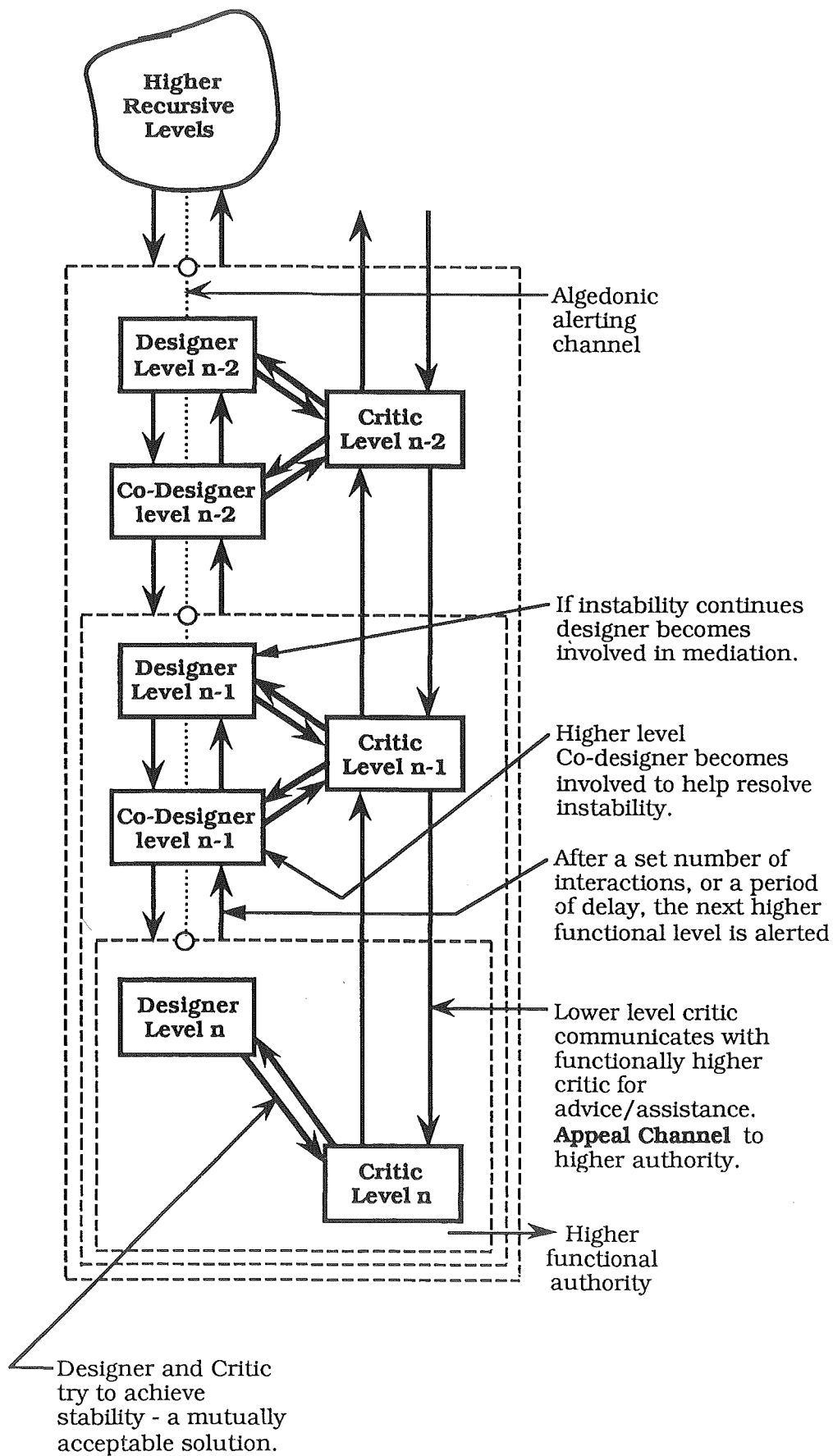


Figure 5.5 Control system for Designer - Critic Interaction

#### **5.4.4 Designer - Co-Designer Interaction**

In this case the designer and the co-designer are unable to develop a common belief about the necessary system of structural and functional properties necessary to satisfy the client's requirements. Figure 5.6 shows the necessary control diagram.

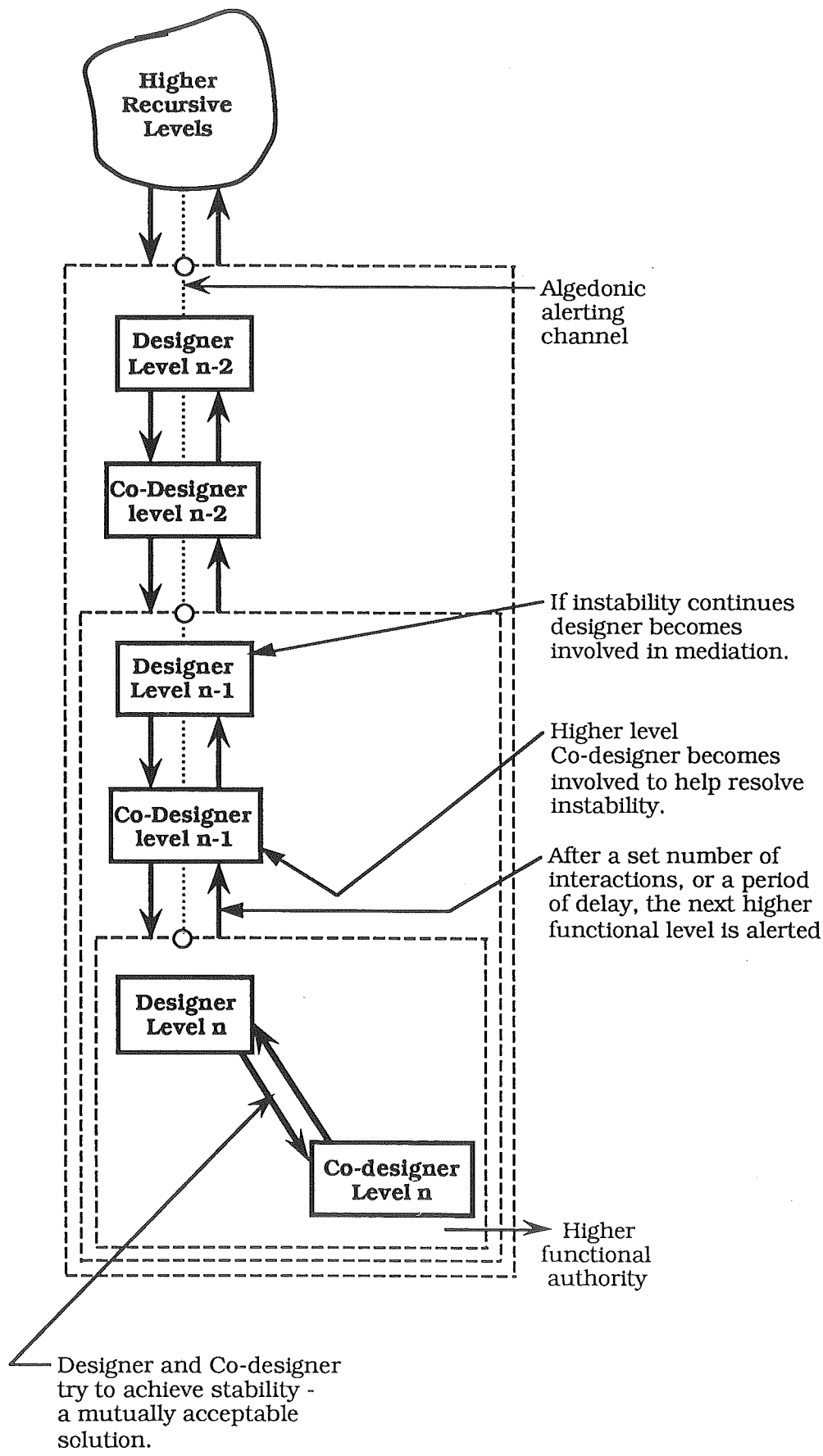


Figure 5.6 Control System for Designer - Co-Designer Interaction

#### **5.4.5 Designer - Functional Expert Interaction**

The role of the functional expert is to provide the designer with information on the capability and possible potentiality of his functional area, therefore, no disputes are likely.

#### **5.4.6 Designer - Belief Expander Interaction**

As with the case of the functional expert, the belief expander's role is simply to provide information (by way of suggestions) to help in the development of the designer's hypothesis. As such no disputes are likely.

#### **5.4.7 Designer - Sub-Designer Interaction**

The relationship between the designer and his sub-designers is essentially the same as the one he has with the client, except for one very significant difference. The designer must set a set of functional and structural properties for each of his sub-designers to satisfy, these properties are defined to ensure that each of the recursive dimensions will integrate correctly. Potential difficulties exist if the sub-designer is of the opinion that the set of functional and structural properties set by the designer are unachievable. He must negotiate with the designer, as in the designer - client relationship, yet because of their slightly different relationship instability may occur if they disagree about the ability to achieve a particular set of properties.

Figure 5.7 show the control system appropriate to this interaction, essentially it is the same as the designer - co-designer control system.



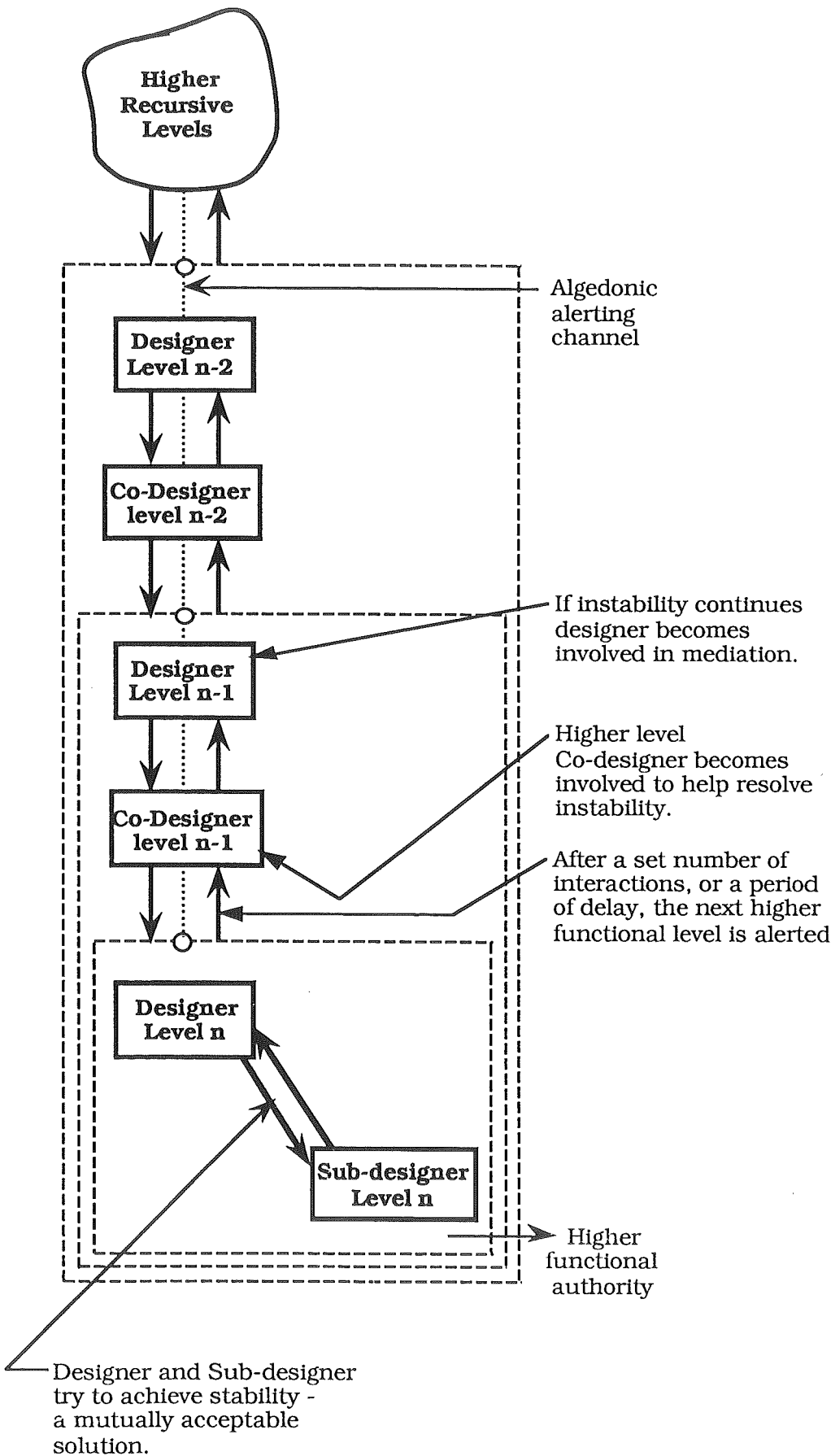


Figure 5.7 Control System for Designer - Sub-Designer Interaction

#### **5.4.8 Designer - Design Hypothesis Freezer Interaction**

This interaction provides a very real possibility for instability. This will result from the designer disagreeing with the DHF's decision to freeze any further development of the hypothesis development process.

The control system is once again the same as for the designer - co-designer situation, except now the role of the DHF may well be filled by the next higher level co-designer or designer. The control diagram, figure 5.8, is shown for the general case when the DHF is not filled by those members of the next higher level.

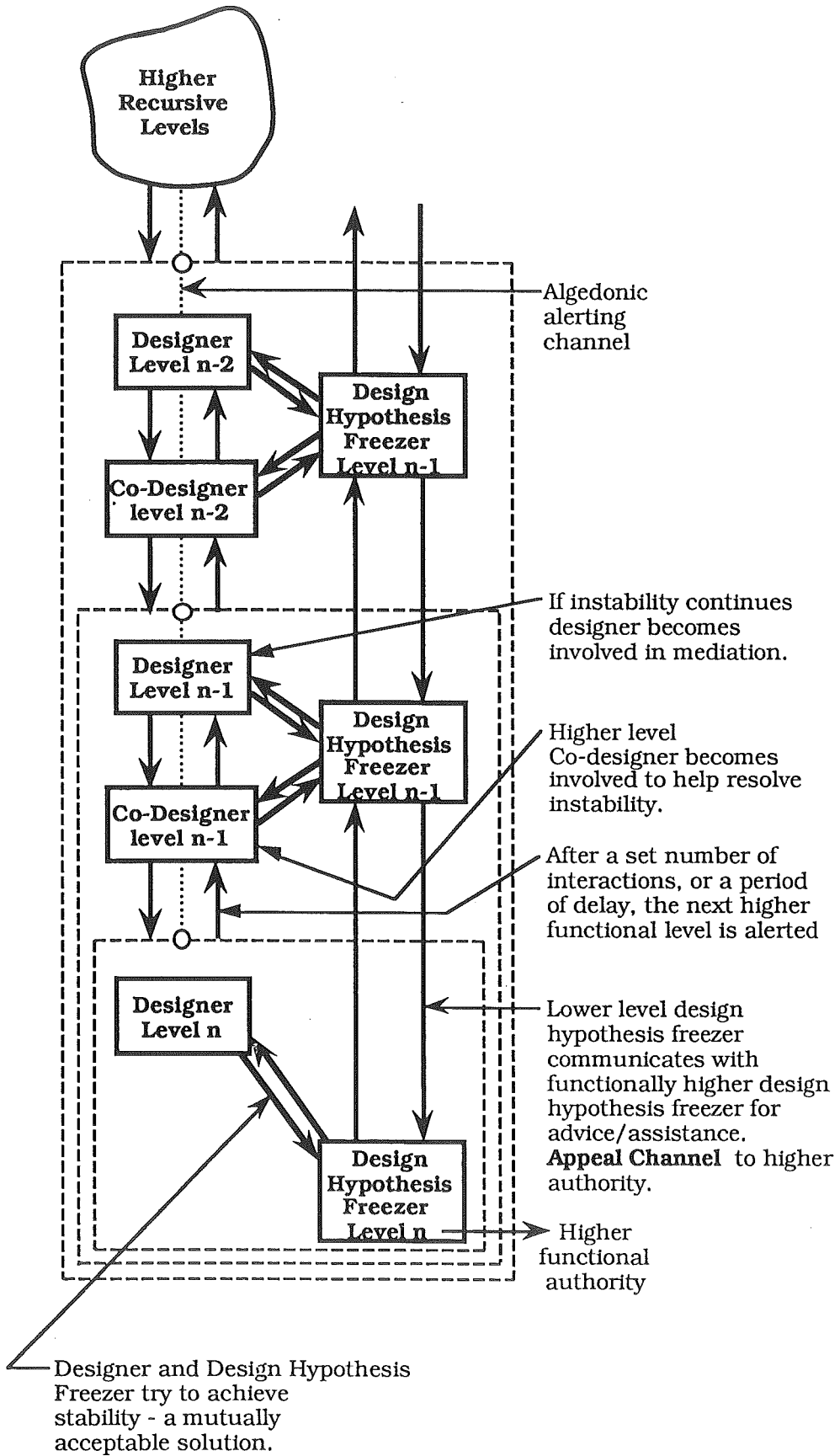


Figure 5.8 Control System for Designer - Design Hypothesis Freezer Interaction

#### **5.4.9 Designer - Documentor Interaction**

The role of the documentor is to communicate the designer's hypothesis to other elements of the organisation or to the environment. Apart from the documentor's work being checked by the designer, and changes ordered, no likelihood of instability exists.

#### **5.4.10 Designer - Administrator Interaction**

The administrator represents a go-between, between the designer and the organisation, he is also the manager of the communication process, thus it is conceivable that conflict may occur for one reason or another. Figure 5.9 represents an appropriate control system for instabilities occurring between a designer and his administrator.

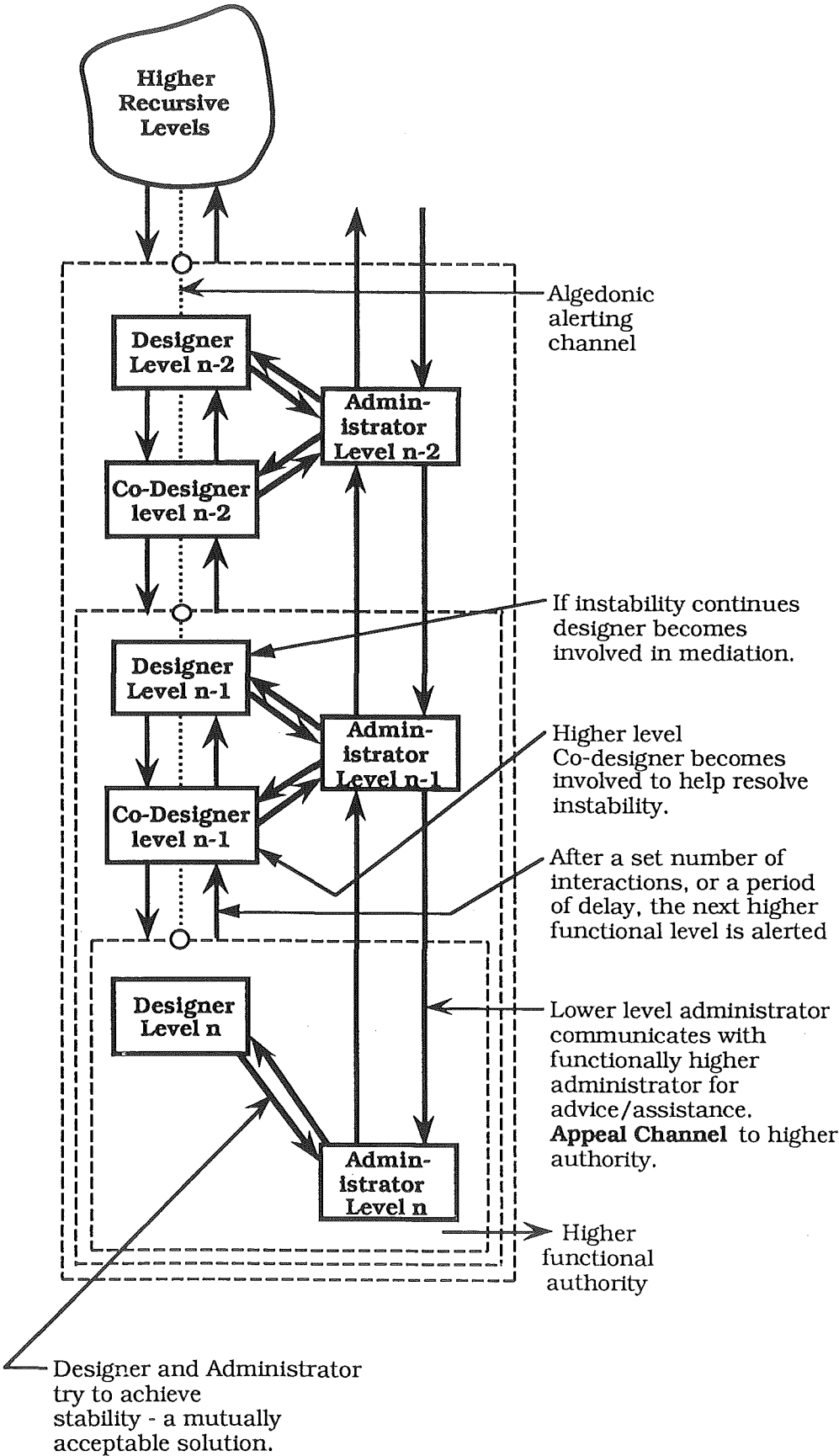


Figure 5.9 Control System for Designer - Administrator Interaction

#### **5.4.11 Team Member - Developer Interaction**

The Developer is external to the hypothesis development project, he finds tools to improve the process, rather than contributing to it. This outside looking-in role, means that instability in his interactions with members of the *team* is virtually impossible. His role will in actual fact be to develop the control systems outlined above, in line with the requirements and culture of the organisation.

The structure of the hypothesis development system, outlined in this thesis, is one of communicating beliefs as appropriate to specialist roles. These various communications feed into the designer who acts to integrate them in to his final design hypothesis. In doing this disagreement over the extent of the integration is bound to occur, the previous section describes control systems for coping with this problem. The following section outlines how these control systems, and the clear structure of the PDM, may allow for a computer based management system for the design process to be developed.

### **5.5 A Computer Driven Purposeful Design Model**

While the integrated hypothesis development model developed in this thesis, in the form of the PDM, does not require a computer to run it, it is possible to envisage it being used to develop hypothesis-development management-software. In such a system the model's logic would be embedded in a system which operates externally to any other software.

In such a system the designer would be able to sit down at his computer at the beginning of a project and call up a tutorial on how the system operates. He could then commence the process with the computer system prompting him on the steps to take, and possible tools to assist him in his task. Once the designer has developed his initial hypothesis (probably on CAD) he could inform the system that the design was ready for release to the critics. The system would probably query him on which critics should be alerted, as well as suggesting those used in the past.

Once the hypothesis is released, the management software would inform the appropriate critics of their tasks, and monitor the time taken to examine the designer's first attempts, reminding the critic at set periods of time if no attempt to access the file is made. In this way the system would ensure that the development process is kept going and that no important steps are missed. After the critic has completed his task (for the first time) the system would alert the designer to the fact and the process would be repeated for a modified hypothesis.

The management software would be programmed with the interaction control logic, and would act as described previously if the pre-set number of interactions or period of delay is reached.

The advantage of having the management software external to other software, such as CAD, means that the designer, critics etc, are free to continue using other computer based tools developed to improve their individual performances.

The five chapters presented to this point have described the integration problem as it exists at the begin the 1990's; defined concepts and terms applicable to that problem, presented theories which offer ways of overcoming the difficulties; and finally put forward a model for integrating the hypothesis development process. This process being applicable to situations of designing, planning or diagnosing.

It has been said that the model is additionally a tool for integrating the diversities of any modern organisation. The last part of this thesis will now take the Purposeful Design Model and apply it to real life situations. The investigations carried out, due to the nature of the project, only show the use of the PDM as a diagnostic tool, however, it is hoped that the examples given will demonstrate how useful the model would be in managing a project from its inception.

The case studies to be presented here are very different in their background. The first concerns the financial collapse of *Rolls-*

*Royce* in 1971, the second concerns the destruction of an English chemicals factory in 1974.

Finally the thesis will conclude with an analysis of a project carried out by the New Zealand Railways during 1989/90. The analysis looks at the deficiencies in the hypothesis development process within the mechanical engineering office of New Zealand Railways, and attempts to relate these to the organisational structure of the Railways. The information for the analysis is the result of extensive interviewing of Railways staff by the author, who was fortunate during the course of his investigation to gain access to employees at all levels of the organisation.



## CHAPTER 6

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### CASE STUDY ONE: THE COLLAPSE OF ROLLS-ROYCE

#### 6.1 Introduction

On February 4 1971, one of Britain's most respected companies, Rolls-Royce Limited, passed from the hands of the public to those of Her Majesties Government (HMG). The events that led to this situation are complex and involved, this review of those events, will focus on the salient points made in a report by R.A. MacCrindle (Q.C.) and P. Godfrey (F.C.A.) dated 4 May 1973; titled

*Rolls-Royce Ltd: Investigation under section 165(a)(i) of the Companies Act 1948 [80].*

The aim of this review is to show how the Purposeful Design Model (PDM), based on the work by Ackoff and Emery, can be used to identify weaknesses in hypothesis development situations, and consequently its potential for use in improving this process, such as in the case of product development.

#### 6.2 Short History of Rolls-Royce

Rolls-Royce was incorporated on 15 March 1906 by C.S. Rolls and Henry Royce with the basic aim of producing and selling motor vehicles. Within a very few years Rolls-Royce had established itself as a manufacturer of very high quality cars.

With the outbreak of World War One in 1914, Rolls-Royce set about designing their first ever aero-engine. This first engine known, as the Eagle, was the first of a long line of Rolls-Royce V12 aero-engines, which eventually evolved into the very successful PV12, or Merlin as it became known. In total 52 marks of the Merlin were built between 1939 and 1945, totalling some 166,000 engines.

Rolls-Royce first became involved in the problems of jet propulsion in 1938, and in 1943 was given the responsibility of building the W2B (Welland) gas turbine, for the Gloster Meteor. As a result of

this involvement Rolls-Royce became pre-eminent in the field of jet propulsion.

After the Second World War, Rolls-Royce decided to continue its aero-engine work and to exploit the lead it had gained in the field of gas turbine technology, by attempting to break into the civil aero-engine market. By the end of 1963, well over 50% of all gas turbine powered aircraft, sold in the West, were powered by Rolls-Royce engines . Thus the aero-engine had become the major product of Rolls-Royce, although the production of luxury motor cars had continued.

In 1966 Rolls-Royce purchased *Bristol Siddeley Engines Limited*, its only competitor in the United Kingdom. This take-over was essentially defensive and intended to stop the rapidly expanding American engine manufacturers from gaining a foot hold in Europe.

In March 1968, Rolls-Royce signed a contract with Lockheed to supply a large number of RB211-22 advanced technology engines. The terms of the contract and the required level of innovation were formidable, however, this was the break Rolls-Royce had been looking for for some time, and was met with great enthusiasm by the company and country alike. The development of the RB211, to satisfy the contract with Lockheed, was what finally led to the financial collapse of Rolls-Royce in 1971. The rest of this review will now look at why a well established and apparently great company allowed the development of one engine to push it into bankruptcy.

### **6.3 Product Development**

The development of any new product is a complex and uncertain exercise, requiring the skills of a large group of people, which must be integrated into a team for the period of development and subsequent production.

The development process is essentially one of decision making and consequently the quality of the decisions made has a massive influence on the quality of the development cycle. Good decisions

can lead rapidly to well designed products, whereas ill informed or unfocused decisions can lead to expensive misdirected effort. The Rolls-Royce RB211 is an example of the latter.

6.3.1 RB211 Contract and Development

In an industry where decisions about new product development can not be taken lightly, due to the massive outlay required to cover development costs, what were the factors that motivated Rolls-Royce to embark on the development of the RB211 ?

In 1965 Rolls-Royce's predominate income earner was the production of aero-engines, although the manufacture of luxury motor cars was continuing. Figures 6.1 and 6.2 show the structure of Rolls-Royce at two levels of recursion.

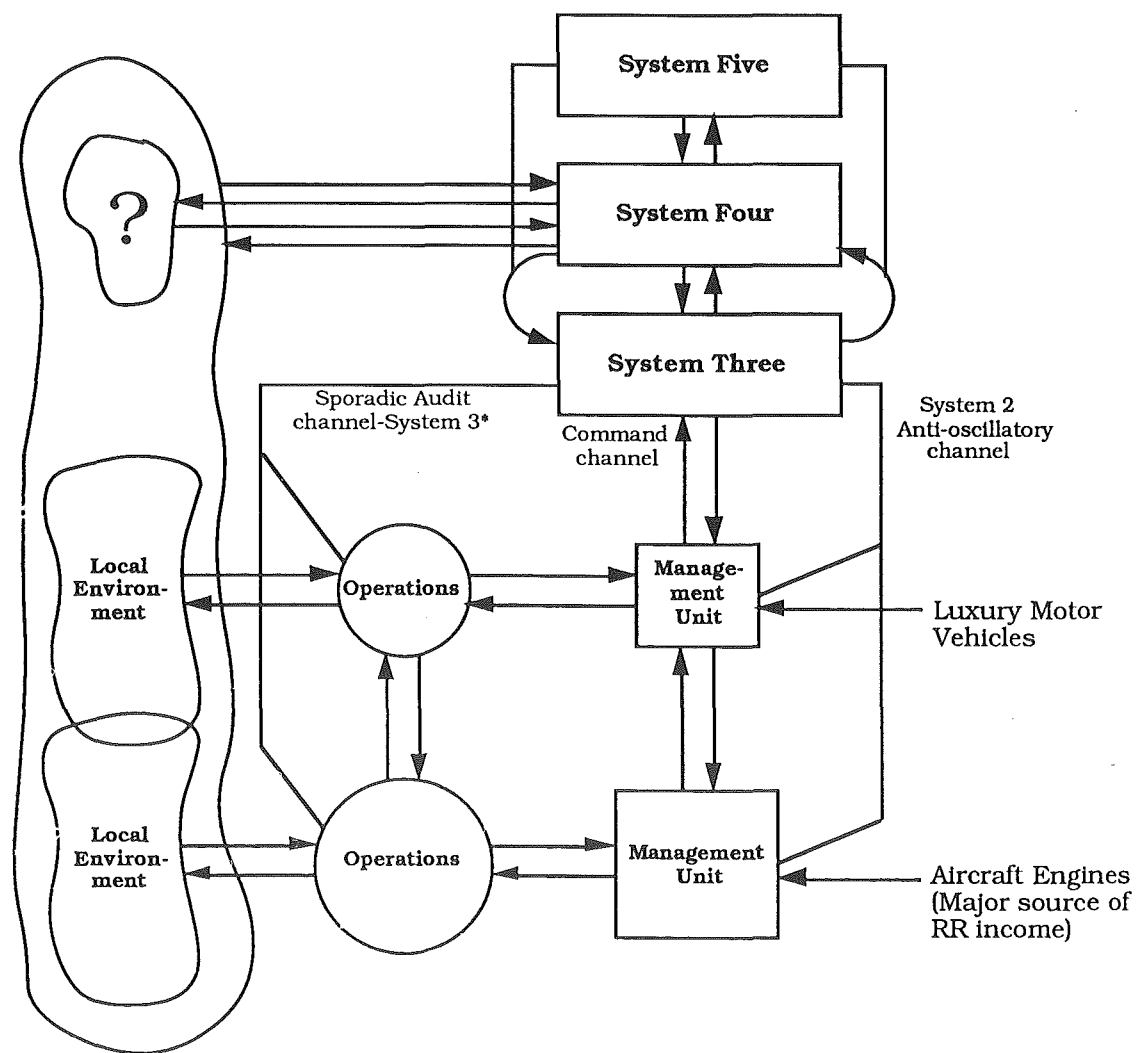


Figure 6.1 Recursion 0 - Rolls-Royce

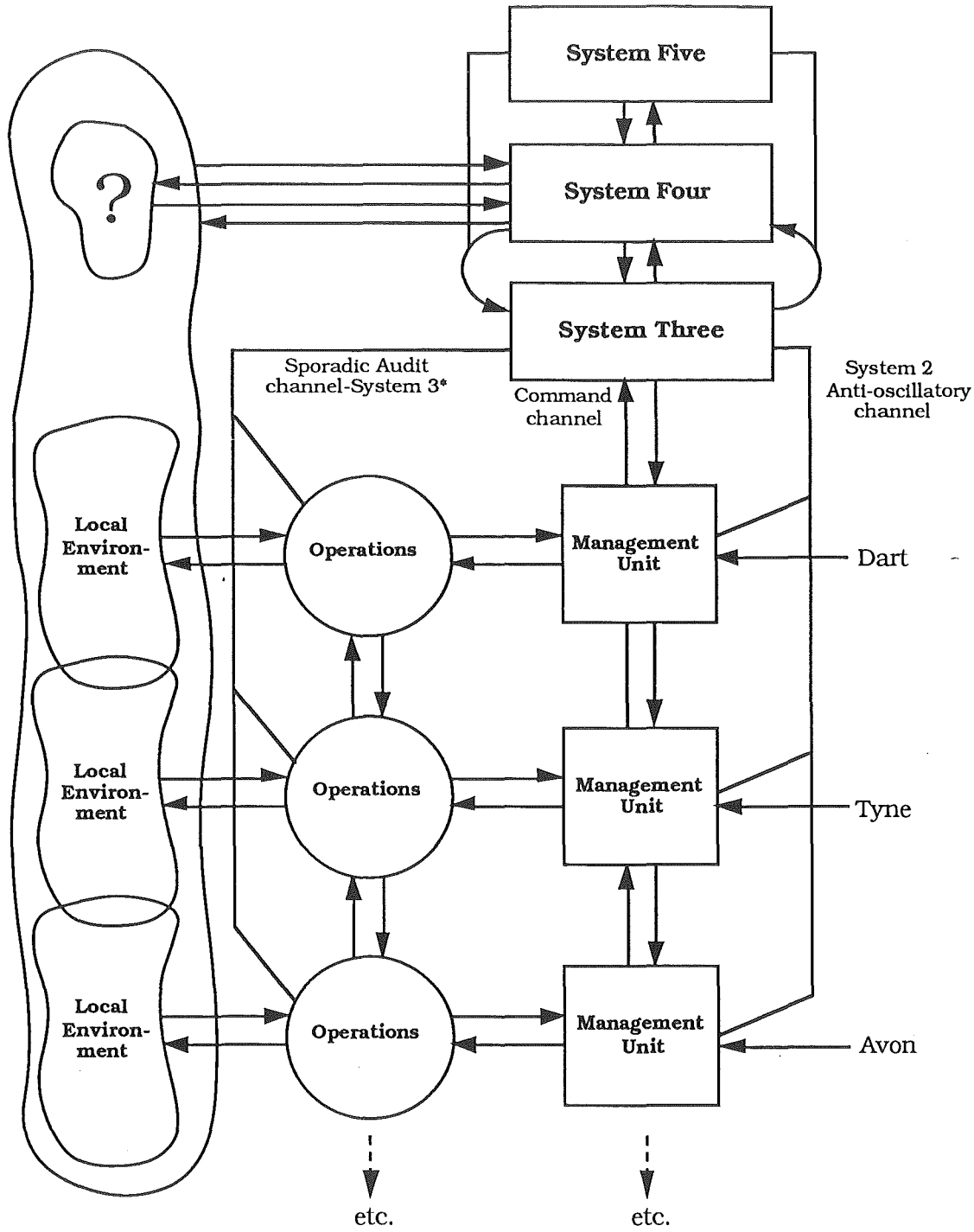


Figure 6.2 Recursion 1 - Engine Production

In 1967 market research in the aero-engine recursion, showed that over the next five years the contribution of existing production engines, to corporate sales, would fall from £95.4 million to £35.4 million. At the same time, investigations into the world wide aircraft and engine market, showed that the future lay in the manufacture of *Big* engines. Failure to obtain a share of this developing market, would result in Rolls-Royce losing its place in

the major league of aero-engine manufactures. The belief held by two of the big players in Rolls-Royce, namely *Sir Denning Pearson*, Rolls-Royce Chief Executive 1957-1970, and *Sir David Huddie*, Managing Director of Derby Engine Division 1965-1970, was that without a *Big Engine* Rolls-Royce would lose its world wide reputation for excellence and innovation.

In March 1967, before any development work had begun on developing a *Big engine*, a paper was prepared which looked at the company's ability to finance the development of such an engine, and it was decided to offer specific prices for the yet undeveloped engine, to Lockheed for their L1011 project.

Rolls-Royce were confident that they could produce a technologically advanced engine, to a strict schedule, and at a cost that would yield them a healthy profit. As a result of this project Rolls-Royce would maintain its position in the rapidly developing industry. At that stage development costs were calculated to be about £30 million or about  $\frac{1}{3}$  the value of Rolls-Royce.

It was at this point that Rolls-Royce made their first mistake. In 1966 a report had been completed titled *Report of the Steering Group on Development Cost Estimating*. In this report it was stated that the cost of development projects as a ratio of the initial estimates, was on average 2.8; but of course some projects were underestimated by a factor of five and occasionally more. But Rolls-Royce had a public image that was of splendid and exceptional status, and was generally considered as safe as the *Bank of England*, there was a general belief that Rolls-Royce was capable of almost anything.

This belief was further exacerbated within Rolls-Royce by the success of several of their earlier development projects, particularly the Spey.

*We launched the Spey in about 1962... We forecasted that the launching costs would be £30 million approximately. When the end of the day came we had spent £30 million approximately. It was quite remarkable, so remarkable in fact that we even had teams going around saying **Look. This is the way to***

*calculate the development costs of an engine and it works. We know... It undoubtedly gave a great deal of over confidence.*

Although over confidence prevailed, Rolls-Royce were not blind to the uphill battle they had in breaking into the United States market. Their future lay in developing a *Big* engine from scratch, using mostly their own funds, whereas their American competitors were essentially paid to carry out advanced research and development by the United States Government. The result of this U.S. Government policy, was that commercially risky development projects essentially did not exist. Almost all civil engines in America began as defence related projects, followed by massive technology transfer to the development of civil engines. United States Government Policy stated:

*The underwriting of advanced technology is considered crucial to the extent that the United States government has made it clear that short term economic considerations will not be allowed to hold back progress in the field.*

Initially a similar situation had existed in the United Kingdom, since the major customer of gas turbine engines was the Government for military purposes. However, times changed and civil engine sales took over as the predominant income earner, and government policy also changed. In 1958 HMG announced that

*The system of general (fundamental) research contracts placed annually would be replaced by a system of more specific contracts for items of work which the ministry required.*

Thus apart from assistance in launching aid<sup>1</sup>, Rolls-Royce were on their own when it came to civil contracts, and this point was made clear by the various members of HMG.

But the feeling by some executives in Rolls-Royce was that the government would never let their company go out of business.

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<sup>1</sup> Launching aid: an interest-free financial contribution to the launching costs (i.e. costs of design and development, production jigs and tools and learner costs) of a civil aircraft or aero-engine project.

This point was made by Sir David Huddie during the enquiry after the eventual collapse in 1971:

*From a defence point of view Rolls-Royce had to be kept going; the place could not be allowed to stop otherwise the Air Force would stop.*

There was, therefore, a belief on behalf of some executives that the public purse was in effect a Rolls-Royce purse.

There were in effect four major beliefs that brought the RB211 into existence, these have been discussed above, but to summarise they are:

1. A belief that the future of Rolls-Royce was bleak if moves were not taken to obtain a contract for a *Big* engine, an area in which Rolls-Royce had no experience.
2. The reputation of Rolls-Royce as an innovator, and the resultant attitude<sup>2</sup> held by the general population regarding the abilities of the organisation to survive. It should be remembered that members of the main board were essentially members of the public, and in general were of a similar age to the Rolls-Royce company. It is therefore likely that their commercial judgement was somewhat compromised by this ingrained attitude
3. The success of the Spey and other engines during the years leading up to the development of the RB211 undoubtedly resulted in an attitude of superiority, regarding the abilities of Rolls-Royce engineers. This attitude percolating through to the main board, further strengthening their belief in Rolls-Royce's abilities. At no time were the reasons for the success of the Spey compared to the RB211 project i.e. low innovation versus massive innovation in many different areas.
4. The belief about Government based finance may not have been an issue of great importance at the outset of the project. It may, however, have been responsible for people

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<sup>2</sup> An attitude is a feeling that persists over time and various environments.

such as Pearson and Huddie not considering the historical reputation of development projects, as outlined in the Downey report of 1966. The belief may, however, have played a very significant part in subsequent decisions to continue with the project, even when it became obvious that things were going wildly wrong.

It is possible that another belief could be added to this list of four, that being the belief that Rolls-Royce had the required manpower to undertake a project of this scale. As it turned out, they did not, and throughout the course of the project they were severely short of staff in the stress office, particularly those with any degree of experience.

Thus based on beliefs about Rolls-Royce held by the members of the main board, a contract was signed with Lockheed in March of 1968. The contract was for the construction and delivery of RB211-22 advanced technology engines capable of producing 42,000 lb thrust as compared to the 21,800 lb thrust of Rolls-Royce's previous biggest engine.

With regard to the Purposeful Design Model the events that led up to the signing of the contract show major violations of the model. These violations will now be discussed showing the power of the PDM as a diagnostic tool.

### **6.3.2 Violations of the Purposeful Design Model**

The Purposeful Design Model is recursive in nature, with each level having a different focus, yet utilising the same structure to solve its particular problem. Although the model is recursive, there is no reason to expect that each of the interactions will occur at the same frequency for each of the different levels. For instance, at the highest level, the Designer-Client interaction will obviously dominate, whereas at the lower levels, very little contact with the client is likely. The Designer-Functional expert interaction will also be of utmost importance at the highest level, as this essentially represents a feasibility type interaction. In this interaction the abilities of the organisation are considered in



relation to its abilities to produce a new artifact, while maintaining its own viability. While the Designer-Critic relationship at this level will be concerned with ideas well removed from material world, but rather critical review, by the functional experts, on the organisations abilities to realise the designers hypothesis successfully.

Organisational information for the purposes of corporate decision making is based on the flow of information from the various aspects of the company. In a project type company, the quality of information flowing out of each project will have a major effect on the quality of decisions made at corporate level. Consequently, if information is supplied in an inconsistent or unstructured manner, to the corporate decision makers, then it makes it impossible, or at least very difficult, for them to assess the true position of their organisation. The role of Administrator in the PDM is designed to ensure that information supplied to the company from the project is in a form understandable to that organisation. Rolls-Royce did not require consistent reporting from its units, rather it allowed them to adopt whatever systems they desired.

With regard to the RB211-22 project Rolls-Royce experienced difficulties in each of these areas. While negotiating with Lockheed about what was required of a new engine, Rolls-Royce had no difficulty establishing what it was Lockheed required. However, considerable doubt exists as to whether during the feasibility stage, before the signing of the final contract, a real effort was made to assess the effects of, or the real needs associated with such a project.

Technically Rolls-Royce did not have the capability to design or produce an engine of the type proposed. This fact was more than likely masked by the attitudes that had developed within Rolls-Royce, regarding the abilities of its engineers, in light of the Spey project. It would appear that this attitude badly affected the beliefs people had about the extent of the gap between what Rolls-Royce could and could not design.

In terms of financial budgeting and control, Rolls-Royce senior management performed poorly during the feasibility stage, and again this is tied to the attitude these people had toward Rolls-Royce engineers and the company as a whole. When the senior board gave approval for the project to proceed, it was calculated that the cost of developing the RB211-22 would be £60 million, on company assets of £94.2 million. This decision was made with the knowledge of the Downey report in relation to estimating development costs for projects.

When assessing man power requirements Rolls-Royce were again found wanting, as throughout the project the number of staff both in design and stressing, were well below the level considered necessary for a project of the scale undertaken. The inability of Rolls-Royce to perform interactions of the Designer-Functional Expert type effectively was, as previously stated, essentially a result of the attitude they had about the company and its engineers.

In the Designer-Critic interaction Rolls-Royce also performed poorly, during the stage where the project was being developed at a conceptual level, i.e. at the highest level of recursion, several fundamental questions were not asked. One of the most fundamental questions a financial critic could have asked is; *given the project as proposed, what effect would a cost overrun of 10, 20, 50 or 100% have on the viability of the project, or more importantly the long term viability of Rolls-Royce?* During the course of the project, when structural and functional properties were re-negotiated (with Lockheed), such as in the repositioning of the point where thrust was transmitted to the airframe, the effect of this change on the progress or viability of the project were never considered. This situation may never have occurred had effective critic roles been performed throughout the course of the project.

As discussed previously, design in the PDM is seen as a recursive activity, with the designer at each level being responsible for the integration of all the recursive dimensions applicable to his level. It is obvious, therefore, that the higher the level of recursion the

more experienced should be the designer, in response to the nature of the decisions needing to be made.

Rolls-Royce experienced difficulties in this area as well, some of this difficulty was the result of circumstances, but predominantly it was due to the inability of Rolls-Royce to appreciate the importance of the first few recursive layers in this project. The death of A. Lombard was a tragic blow for Rolls-Royce, he was known as a brilliant engineer and a dynamic leader, always capable of achieving optimal performance from his highly trained men. Undoubtedly the inability of Rolls-Royce to replace this man, placed yet a further hurdle in the path of success of the RB211 project. Without his presence, or someone similar, the project lacked the experienced integrating and leadership skills necessary at the very highest levels.

Rolls-Royce virtually starved the RB211 project of experienced engineers during the early stages of the development project. As stated in the report to the enquiry

*Reorganisation of Derby Engine Division resulted in invaluable experience of seven design personnel not being allocated at the critical early stages.*

This shortage of experienced engineers was further exacerbated due to the fact that:

*he (Huddie) and a number of his senior engineers found it necessary to travel abroad frequently... It meant that the division was starved of the directing mind of its managing director at a vital time.*

Rolls-Royce tried to overcome the continual absence of Huddie by appointing an RB211 programme director, in the belief that it would overcome most of the problems. However, they failed to give him any authority over the executive heads of the various departments. As a consequence, the value of his efforts were dependent on what action Huddie took.

Thus at a time when Rolls-Royce could least afford to, they lost one of their most valuable engineers and starved the project of the

talent that it needed to establish a firm foundation, from which to launch a full scale design and development project.

#### 6.4 Summary and Conclusions

From its humble beginnings in 1906, to a leader and innovator in the area of jet propulsion in the 1960's, Rolls-Royce had developed a reputation in Britain and around the world, as a leading force and producer of high quality engines. The decision to go ahead with the RB211 was based on the firm belief, that Rolls-Royce would fall from its elevated position if it could not produce an engine for the developing *Big* engine market.

The decision was clearly influenced by the success of previous Rolls-Royce projects such as the Spey and a lack of understanding of the financial consequences should anything go wrong. A series of Beliefs and Attitudes are responsible for the series of decisions which were eventually to bring the RB211 into existence.

These Beliefs and Attitudes had played a significant role in getting Rolls-Royce to the position it enjoyed as a leader in its various industries. They had made Rolls-Royce into a leader and innovator, it had worked in the past for a number of reasons. It didn't work in the case of the RB211. The RB211 project was necessary for Rolls-Royce to survive, the extent of the fall was firmly attributable to poor management.

The PDM has been used to show how the effects of the various beliefs and attitudes, along with the problems in management, manifested themselves in the RB211 project.

If Rolls-Royce had had an explicit model of the product development process and the types of interactions which should occur, then it is plausible that the effect of the beliefs and attitudes would have been significantly diminished. It is also likely that the project would have been managed more effectively from the outset, if such a model have been employed.

## CHAPTER 7

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### CASE STUDY TWO: THE FLIXBOROUGH DISASTER

#### 7.1 Introduction

Saturday June 1st 1974, is a date the residents of the small English village of Flixborough will never forget. On that day, at 4.53 p.m., a nearby chemical plant exploded, killing some 28 people, injuring another 36, and damaging a total of 1,821 houses in nearby towns.

The resulting inquiry concluded that the cause of the explosion was the catastrophic failure of a 20 inch diameter connecting pipe. The result of which was the formation of a massive vapour cloud, due to the release of cyclohexane at a pressure of at least 8.8 kg/cm<sup>2</sup> and a temperature of 155°C.

The aim of this review is to show how an incomplete set of beliefs resulted in a violation of the Purposeful Design Model, and thus caused this tragedy to occur. The information used in this review has been obtained by referring to the findings of a Department of Employment Court of Inquiry, simply titled *The Flixborough Disaster* [81].

#### 7.2 Events leading up to June 1.

On the evening of March 27 a crack was discovered in the fifth reactor of a group of six. From this crack cyclohexane was found to be leaking. As a result of the discovery, the plant was shut down and depressurised ready for a full inspection. The following morning the crack was inspected and found to be about 2.0 m in length, because of the seriousness of the situation a meeting was convened to decide what action should be taken.

Present at that meeting was the General Works Manager, a Mr. Beckers an experienced chemical engineer. Also present was Mr. Bell, one of the plant managers, also an experienced chemical engineer, the Deputy Works Engineer and Services Engineer, Mr.

Boynton, qualified with an ONC (electrical), along with; Mr. Cliff another plant manager and a chartered engineer; Mr. Blackman, an engineer responsible for several of the production areas; and Mr. Halderit, a commissioning engineer.

It was decided at that meeting that the cracked reactor should be removed for inspection, and that a by-pass assembly should be constructed and fitted to allow production to continue. At no stage was it decided to inspect the other five reactors to check for similar cracks.

As a result of this decision a dog legged section of 20 inch diameter pipe was constructed, the dog leg being necessary to connect the outlet of the number four reactor to the inlet of the number six reactor, these being vertically displaced from one another. Figure 7.1 shows the arrangement.

Calculations were made to see if the 20 inch pipe was large enough to handle the required flow and withstand the working pressure as a simple straight pipe.

The dog legged pipe consisted of 3 welded sections, connected to the reactor inlet and outlet via bridging flanges and expansion bellows. After construction and fitting, the system was pressurised with nitrogen to 4 kg/cm<sup>2</sup>, as per the usual start up procedure, and tested for leaks. Leaks were found and the dog-leg was removed, re-welded and then fitted once more. Again the system was pressurised to 4 kg/cm<sup>2</sup>, no leaks were found so a further leak test was conducted at 9 kg/cm<sup>2</sup>. Once again no leaks were found and start-up continued as normal. The system continued operating until May 29 when it was shut down to allow repairs to be made on an isolating valve. Those repairs were made on the 30th and 31st of May, the subsequent start up commenced in the early hours of June 1st.

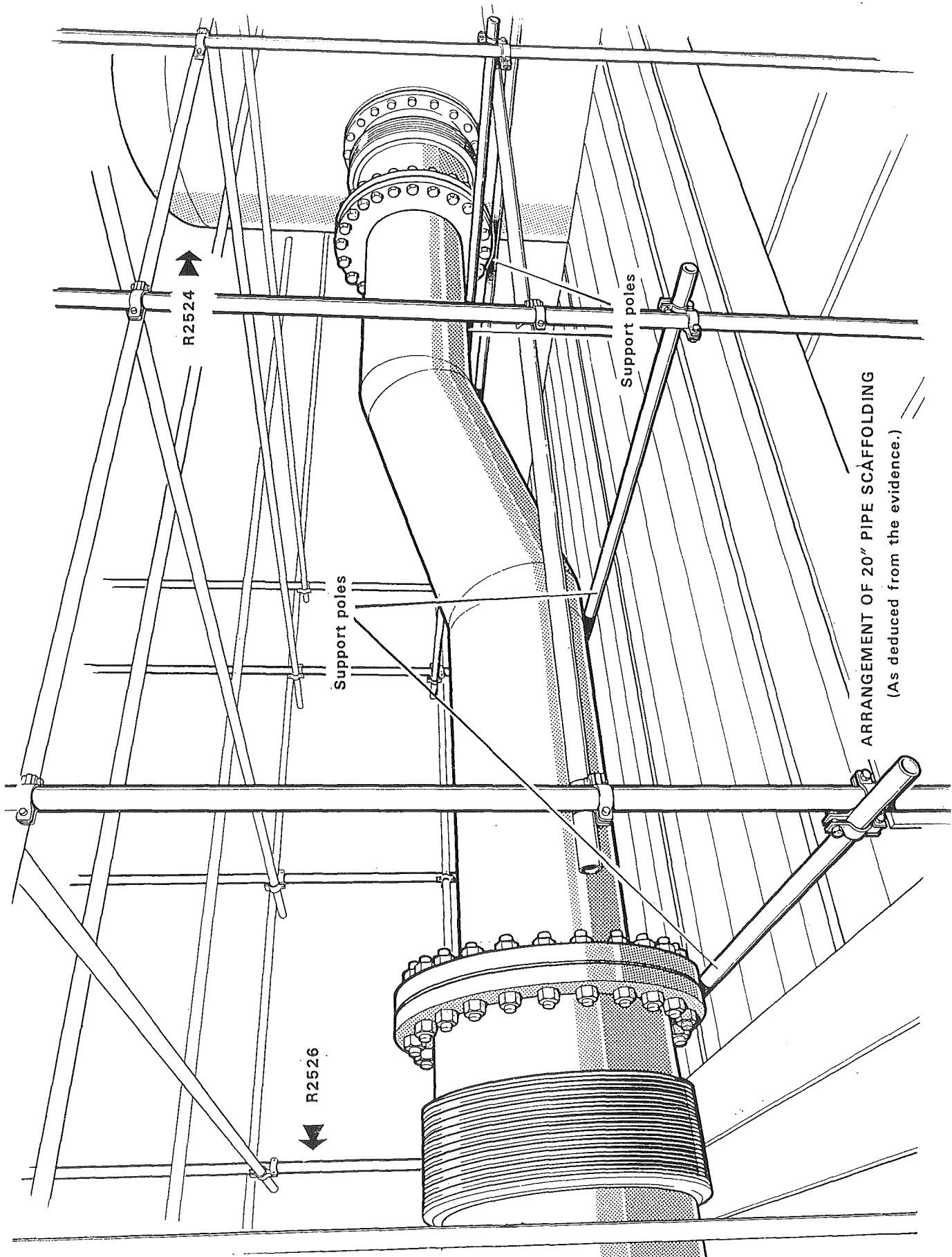


Figure 7.1 20 Inch Dog-Legged Connecting Section [From 83]

Problems were encountered during the start up procedure, with the pressure rising much more rapidly than normal, this was controlled but start up still did not proceed as usual. Throughout the remainder of the start-up system pressure continued to fluctuate, often at levels inconsistent with the working temperature of the system. While these pressures were higher than normal they were not considered alarming. The events of the final few hours are unknown, all control personnel were killed and the relevant instrumentation and records were destroyed in the explosion. Although the final events are unknown, it was felt by those working on the earlier shift that further difficulties were probably encountered during the remainder of the start-up process.

### **7.3 Conclusions of the Court of Inquiry**

During the course of the Court of Inquiry there were essentially two different scenarios considered. The first of these was that a pipe other than the 20 inch connecting section had failed prior to the main explosion. Events associated with this other pipe, a smaller 8 inch pipe, had however brought about the eventual failure of the larger pipe. This hypothesis was eventually rejected on the grounds that it required too many unlikely events to occur for it to be plausible, thus the second series of events was ultimately endorsed by the court of inquiry.

The second scenario, hypothesised that the 20 inch by-pass pipe ruptured as a result of internal pressure and temperature that were likely to have existed during the final shift at Flixborough. The rupture, it was concluded, was most probably the result of an initial jack-knifing at a pressure less than the relief pressure of 11 kg/cm<sup>2</sup>. The jack-knifing was considered to be the result of gross permanent deformation in each of the attached bellows.

Considerable experimental work was performed regarding this theory, in particular by *Professor Newland* of the *University of Sheffield*. In his report to the Court of Inquiry, Professor Newland concluded that the above situation would be likely to occur at moderate temperatures and pressures, and was made more likely



by high bellow stiffnesses. This conclusion was accepted by the court and ultimately became the findings presented to the Minister for Employment, Michael Foot. Summarising the court stated that:

*The disaster was caused by the introduction into a well designed and constructed plant of a modification which destroyed its integrity.*

To ensure plant integrity was not violated in future cases, it recommend that:

1. *Modifications should be designed, constructed, tested and maintained to the same standards of the original plant, and*
2. *That modifications should be inspected by an appropriate authority before recommencement of production.*

With regard to the management of Flixborough the court concluded:

*At the time of the installation of the By-Pass the key post of Works Engineer was vacant and none of the senior personnel of the company, who were chemical engineers, were capable of recognising the existence of what is in essence a simple engineering problem let alone solving it.*

The court felt that in future:

1. *Special care should be taken if decisions have to be taken which would normally be taken on the advice of an absent individual, and*
2. *That the training of engineers should be sufficiently broad to allow engineers to understand problems associated with other disciplines.*

The background to the disaster has been laid and the findings of the court of inquiry presented, the decisions that led to the construction and fitting of the by-pass pipe will be analysed in terms of the Purposeful Design Model and the various participants sets of beliefs.

## 7.4 Analysis of Decision Process

The decision to remove the number five reactor and replace it with a dog-legged by-pass pipe was a management decision. As was stated in the findings of the court of inquiry, no one present at the meeting, where the decision was made, were technically qualified to make such a decision. That decision was made, because those present felt that the solution to the problem was a *simple plumbing job*, clearly indicating that none of those present had an adequate set of beliefs to foresee any of the possible problems and the consequences of such problems.

The reason for a lack of an adequate set of beliefs, on behalf of the decision makers, lay in the fact that the majority of those present were chemical engineers. Chemical engineers are trained to develop the system design for chemical plants i.e. sizing of compressors, condensers etc. The detailed decisions for such things as pipe sizes are left to mechanical engineers. This situation can be explained clearly using the PDM; the chemical engineers perform the designer roles at the highest levels of recursion, where their belief system has been developed throughout their training and years of experience. Mechanical engineers perform the designer roles at the lower levels of recursion, where detail such as pipe sizing is determined. To perform this role, the mechanical engineer will have developed a belief system appropriate to the task, this being developed through his training and the experience gained at the very lowest levels of recursion.

The court of inquiry recognised this disparity of beliefs when it recommended that in future,

*That the training of engineers should be more broadly based.*

The result of this would be a wider based set of beliefs. This would ensure that a chemical engineer would be more familiar with the issues at a lower level of recursion to that at which he would normally work.

Essentially the problem at Flixborough was caused by chemical engineer executives, transcended to a level of (design) recursion beyond the breadth of their belief system. This was able to happen because there was no mechanical engineer present, the position normally filled by a suitably qualified engineer being vacant due to difficulties in replacing the previous incumbent.

The limited belief system of the executives, was again exhibited when they entrusted an obviously under qualified individual to undertake the detailed design of the by-pass pipe. In doing this they expected an individual with a totally inadequate set of beliefs, to design a section of pipe they incorrectly considered to be *just a piece of plumbing*. Thus the absence of a suitably qualified mechanical engineer, with the required belief system, meant that no critic role was performed at the *higher* executive level, and thus the requirements of the integrated PDM were not satisfied. Such an absence, also meant that the design levels of recursion could not be vertically integrated adequately, with regard to the necessary design, this being due to the inadequate belief system of the by-pass designer, so again the PDM was violated. It was this problem that resulted in the destruction of the plant's integrity.

One other significant violation of the PDM, occurred at the level of detailed design of the by-pass pipe. This violation was the exclusion of the critics role, which in this case would generally take the form of the appropriate design standards. The pipe designer's belief system was obviously so lacking that no reference at all was made to an appropriate British Standard or designer's guide. This omission did not only affect the design of the dog-legged pipe, but also the way in which the two expansion bellows were used. The manufacturer's recommendations stated that the bellows should not be subject to any form of shear stress, however, in the resulting design they were subject to a shearing force of 2 - 8 tonnes. The designer's chalk sketch on the workshop floor, and his rather simplistic calculations, clearly indicates that he failed to appreciate the seriousness of the problem and that his belief system was inadequate for the task.

## 7.5 Summary and Conclusions

The Flixborough Chemical Works was a site where tonnes of highly volatile chemicals were stored and processed, thus any sort of explosion was likely to result in a major mishap. On June 1st 1974, the residents of the nearby village of Flixborough, along with the residents of several other villages in the vicinity, experienced the effects of such a mishap. The resulting inquiry concluded that the disaster was due to an inadequately designed section of pipe, which had been constructed to by-pass a failed reactor.

This review has shown that the decision to replace the cracked reactor with a by-pass pipe, and its resulting design and construction, were due to a total lack of appreciation of the scale of the problem. This lack of appreciation being the consequence of an incomplete set of beliefs by those involved. The lack of a suitably qualified mechanical engineer ensured that a correctly integrated set of beliefs could not be achieved, in the time frame considered acceptable to those involved. Had those involved had an explicit model of the decision making process, one that ensured that an integrated set of beliefs appropriate to the situation existed, then it is likely that the rushed decision, that was made, would have been delayed. The use of such a model should have ensured that the appropriate expert knowledge would have been sought, thus ensuring that a complete set of beliefs necessary for making and following through such a decision existed. The Purposeful Design Model is such a model, and attempts to show what roles must be fulfilled if an integrated set of Beliefs is to be achieved with reference to a particular goal.

## CHAPTER 8

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### NEW ZEALAND RAILWAYS: A PRODUCT DEVELOPMENT EXAMPLE

#### 8.1 Introduction

The process of product development is central to an organisation's long term viability, whether it be the design of consumer acceptable products, in the manufacturing industry, or the design and construction of products to facilitate the efficient undertaking of some other core business. The New Zealand Railways falls into the second category, where the design and construction of new wagons and carriages supports their rail operations.

The Purposeful Design Model was initially intended as a model for developing integrated design hypotheses. To demonstrate the use of the model in a practical design situation, it was considered necessary to find a product development situation and follow the process as it evolved. While the PDM was not used to manage the project that was finally investigated, its power as a diagnostic tool is once again demonstrated.

New Zealand Railways kindly gave permission for the author to interview any member of its staff, regarding the development of a *new* type of freight container; the GST. Ultimately eighteen personnel were interviewed, ranging from shop floor workers in Christchurch, to the Chief Executive Officer and corporate management personnel in Wellington. Additionally several other individuals provided information, useful to the investigation, during impromptu telephone conversations. Significant additional information came from public arena sources such as Railways publications, historical reviews and Railways' Press releases.

The purpose of the investigation, while primarily being to demonstrate the power of the PDM, also aimed to investigate if organisational disintegration within Railways was responsible for any of the model's violations. Interviewing, therefore, centred on two issues, firstly the design process used in the development of

the *GST Container* and secondly the organisational structure of Railways, as perceived by those interviewed.

The resulting investigation is therefore divided into these two areas, with this chapter dealing with the historical development of the New Zealand Railways, and the resulting organisational structures during its 120 year history. Using the Viable System Model these structures are investigated and their ability to achieve *technical integration*<sup>1</sup> discussed. The following chapter investigates the design process used in the design of a new container for Railways, and uses the PDM to highlight the causes of design faults, discovered during the course of the investigation. These violations, of the PDM, being related to dis-integrating factors within the Railways' structure.

The information to undertake this study came from a number of interviews, to enable this to be done successfully it was first necessary to become familiar with accepted interviewing techniques.

## 8.2 Sociological Research Methods

The opportunity to interview a large number of individuals, on the functioning of their organisation, is a time consuming and demanding activity. It requires that the time spent, with those being interviewed, is used to maximum effect. To improve the chances of achieving this ends, it was decided to review a cross-section of the literature on *Sociological Research Methods*.

From this literature it was found that the most appropriate form of interviewing technique would be the *Focussed Interview* [82,83,84,85], or *Conversation with a Purpose* [86], as it is sometimes known.

*Here, the interviewer works with a fixed list of questions or problems to be covered, but alters that for each respondent. He also rephrases questions for each respondent. This strategy has the benefit of*

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<sup>1</sup> Technical integration being the integration of the technical process of designing and constructing new wagons and carriages, in order to achieve Railways organisational goals.

*eliciting common information grounded in the perspective of those observed [82].*

*Adjustments to the guide during the interview are carried out by skilful use of the major focussed interview tool, **the probe**: the interviewer prompting for further elaboration of an answer [85].*

It was this type of approach that was ultimately used.

There was evidence to suggest that a number of difficulties could be encountered in undertaking a series of interviews, including

1. *Securing a favourable attitude toward the investigation [83]*
2. *The absence of a common language - restricting the ability to **get down** to details [83,87].*
3. *Setting of interview - finding a familiar and comfortable setting in which to conduct the interview [83].*

Being a university student appears to have enabled the author to overcome these possible problems adequately. Railways has suffered a large number of redundancies in recent years, especially in the workshop areas. The result of this situation seemed to be that individuals were keen to talk, possibly hoping that any advice to Railways management, from the project's findings, might reverse the trend of annual redundancies.<sup>2</sup> Most of those interviewed at the corporation's head office in Wellington were professionally qualified, as such, the project offered the possibility for some external comment on their work, and the opportunity for learning of new ways to improve their performance. Others simply enjoyed the opportunity to talk about their respective jobs. Thus obtaining a favourable attitude appeared to pose no problems. By being a student the difficulty in achieving a common language was also in general overcome. The author was able to discuss easily the details and concerns of those on the shop floor, yet his engineering and management backgrounds allowed him to understand the points of view of professionally qualified engineers and senior managers, within the corporate head office.

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<sup>2</sup> Unfortunately, in December 1990 all personnel at the Railways workshop in Christchurch, where a significant number of interviews were conducted, were made redundant and the workshop closed.

Finally finding a comfortable and familiar setting for the interviews posed no difficulty. Interviews held with workshop employees were conducted in casual dress on the shop floor, while those at the head office were in formal dress in the offices of the individuals concerned.

The purpose of the interviews was to gather information, the opinions on how to record this information varies, with some authors concluding that notes should not be taken during the course of the interview, while others feel that note taking is essential. The solution finally selected, was to make brief notes during the course of the interview and then produce *full* notes as soon as possible. Minimising the time between the interviews and the production of the *full* notes is considered essential, if interviewer bias is to be eliminated [83,86].

Reality is what people perceive it to be, unfortunately people's perception can, at times, be mistaken. From a research point of view this makes collecting useful data difficult, in order to overcome this problem *triangulation* is necessary [82,84]. Essentially triangulation consists of obtaining a number of view points on the same topic, or obtaining supplementary information to verify the views of those interviewed.

The number of interviews conducted in this investigation was relatively high, the time to complete them comparatively short, the techniques discussed above helped to ensure that time was used to maximum effect.

The remainder of this chapter is now devoted to the organisational development of Railways, from its humble beginnings in 1863 through to its aggressive commercial structure in 1990.

### **8.3 New Zealand Railways: 1863 - 1990**

December 1 1863, and New Zealand's first steam locomotive *Pilgrim* made her first trip between the rapidly expanding settlement of Christchurch and the Heathcote River estuary at Ferrymead. Four years later, to the day, New Zealand's first rail



tunnel was opened, linking Christchurch with its port of Lyttelton.<sup>3</sup>

The son of a wealthy English-Jewish family and eventually to become a Premier of the fledgling colony, is credited with being the *Father of New Zealand Railways*. Julius Vogel became New Zealand's Colonial Treasurer in 1869, at that time there was just 74 km of public railway operational, by 1878 however, largely due to Vogel's efforts, a total of 1828 km had been added and was under unified control. In 1870 the *Immigration and Public Works Act* had been passed, under this act the government undertook to construct a network of rail lines throughout the North and South Islands, at that time a total of 1,000,000 hectares and £7.5 million were specified as the maximum amounts available for railway construction purposes.

Thus the foundations were laid for an extensive government financed rail network. From 1870 to the end of the decade, considerable areas of New Zealand were opened up, allowing for the inward and outward transport of people and produce from all areas of the country. However, between 1881 and 1894 the Railways experienced depression and decline, as a result of a worsening public image, a fall in the South Island gold production and depletion of the South's initially fertile soils, resulting in substantially lower farm yields.

In 1886 the *Amalgamated Society of Railway Servants*, the oldest New Zealand Railway Union, was established. The initial concessions won by the union from the Railways management, did much to influence not only the social and political position of the Railways within New Zealand, but also the power of the union within the organisation.

Eighteen Ninety Four saw the appointment of Irishman, Thomas Ronayne, to the position of General Manager. During the years of his appointment, until 1913, he, with the help of improving economic conditions within New Zealand, and the advent of

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<sup>3</sup> The historical background for this chapter is based principally on the book by David Leitch and Bob Stott, titled *New Zealand Railways: The First 125 Years* [88].

refrigeration (first frozen shipment of mutton and lamb to England was in 1882), was able to turn Railways' fortunes around, and in 1897 he was able to announce for the first time a return in excess of the long aimed for 3 percent.

By the early 1900's politicians were beginning to run out of superlatives to describe the improved fortunes of the Railways. Each year's net revenue was exceeding the previous year; with 1910 showing a profit in excess of one million pounds, while 1913's net return of £1.25 million was equal to a return on invested capital of a little over 4 percent. Although freight was a large part of Railways' work, an equally profitable portion was their tremendously popular passenger services, with annual figures being around 7 million persons carried by the turn of the century.

The demand for passenger and freight services was so great that additional services, accelerated timetables, and vastly increased numbers of wagons and carriages, were added in an attempt to soak up the excess demand. World War One stopped all development plans put forward to the Government by the Railways' new General Manager. E.H. Hiley had been recruited from England and his development plans for Railways were far reaching, but at a cost of £3.25 million the war effort was considered a more important option. Hiley's plans were really never developed and his contract ended in March 1919, with him warning the government that the Railways Department would find itself in a £7 million turnover business with equipment that was inadequate to satisfy the needs of a £4 million pound business. Hiley was the first General Manager who recognised that the department needed to be run to suit the customers' convenience and not that of the departments, in this sense he was Railways' first commercial rather than Operating Manager.

The end of war saw a massive influx of vehicles into the country and a subsequent decline in the demand for rail capacity. By 1931 the situation was becoming quite severe, with about 540,000 tons of freight having been transferred from rail to road. The 1931 *Transport Licensing Act* was designed to protect not only Rail; but also limit damage to roads by heavy fast vehicles; to rationalise road

operations and ensure safety and reliability and to require carriers to be insured against liability; and to avoid wasteful duplication of facilities by rationalising road and rail services. In 1936 a rail protection clause was added, giving rail protection against road competition for distances over 30 miles, on routes where rail services existed. This was extended to 40 miles in 1962 and finally 150 km in 1977, before finally being abolished in 1983.

The effect of the 1929 Stock Market crash in America, flowed on to New Zealand and had a severe effect on the Railways. By 1931 the fall in traffic was so pronounced that train miles were reduced by 1.2 million kilometres, in 1932 an additional 1.8 million kilometres were cut. Within two years the number of employees fell from nearly 20,000 to below 15,000.

However, the last half of the 1930's saw recovery and rapid growth in the New Zealand economy. This was also experienced within Railways and resulted in grand plans for the restructuring and development of the department and its network. The Second World War brought an end to this, just as World War One had 23 years earlier. However, the effect of war time petrol rationing and the military's demand for transport, resulted in Railways returning a record financial result in 1944, even though its work force was now some 25% less. Unfortunately the end of the war brought a change in fortunes, as prices for many basic items climbed rapidly, but fares and charges remained unchanged, by 1948 net losses were close to £700,000. The 50's saw the arrival of diesel powered locomotives, which not only cut Railways operating costs in half, but also relieved the pressure on the understaffed maintenance facilities. But improved efficiencies and reduced travelling time did nothing to reduce the trend away from rail, in 1947 some 5 million non-suburban passengers were carried by rail, by 1954 this had fallen to 2.8 million.

Throughout the sixties passenger numbers continued to decline, as did Railways' public image. Railways systematically closed what they considered to be unprofitable lines, regardless of the actual number of daily users, and replaced them with less than popular bus services. Railways did, however, finally get the inter-island

link they had wanted for so long. On the 13th of August 1962 the *Aromoana* entered service, as the first roll-on-roll-off rail and road ferry service across the Cook Strait. In that first year the *Aromoana* carried some 207,000 passengers, 46,000 cars and 181,000 tons of freight. For the first time in New Zealand's history a rail link existed from North Cape to Bluff.

The first half of the 70's saw a *mini boom* in the New Zealand economy, and as a result rail traffic increased, however, because of government policy, Railways deficit continued to increase. Government elected to cover Railways' short falls in return for government fixed charges and prices. Unfortunately the general public perceived this as a subsidy to an inefficient enterprise, rather than as a subsidy to rail users, and thus a form of macro economic control intended to keep down inflation.

Freight levels continued to increase resulting in the railway rapidly becoming clogged to a standstill by goods in transit. Delays became more and more common and customers became increasingly dissatisfied. All this time charges were frozen, the result of this was a continually worsening financial position, by 1976 the annual deficit had increased to \$66.5 million.

October the first 1977 saw the first move in the restructuring of New Zealand's internal transport system, with the extension to 150 km of the previously 40 mile road transport limit. This, it was predicted, would cut Railways goods traffic by 20 percent. Rail charges were also increased, with rates rising by 30 percent on average for freight, and up to 64 percent on average for long distance passenger services. However, a continually worsening financial position, led the then General Manager, Mr. Trevor Hayward to release a booklet titled *Time for Change* [89], written for the Railways three million share holders (New Zealand's population). It explained the social costs that Railways were being expected to cover by Government. As a sequel to this, Hayward released *The Social Role* [90] in 1980, to further indicate the true costs of its services and how the charges for these were far below what they cost, in a number of instances. On top of this, additional social costs borne by Railways included apprenticeship training,

which annually cost the company around 13 million dollars. Railways was essentially providing a technical training school for the nation, with an annual intake exceeding several hundred apprentices, many of these ending up in better paying private sector jobs. Hayward's attempt to bolster Railways' sagging public image, however, did little to quieten its many critics.

In 1981 the government acted to change the worsening situation with its Railways asset, in an attempt to improve its financial performance it introduced the *New Zealand Railways Corporation Act* which defined the functions of Railways to be [Railways Act 1981].

- (a) *To establish, maintain, and operate, or otherwise arrange for safe and efficient rail freight and passenger transport services within New Zealand:*
- (b) *To establish, maintain, and operate, or otherwise arrange for safe and efficient road passenger and freight transport services within New Zealand:*
- (c) *To establish, maintain, and operate, or otherwise arrange for, a safe and efficient ferry service for freight, including the carriage of passengers and vehicles between the North and South Islands:*
- (d) *To provide or otherwise arrange for those ancillary services which, in the opinion of the corporation, are necessary for it to efficiently carry out its functions:*
- (e) *To endeavour to carry on the operations of the Corporation in such a way that revenue exceeds costs, including interest and depreciation; and to provide a return on capital that may be specified from time to time by the Minister of Finance.*

Thus the foundations of change were laid, as Booz, Allen Consultants stated in their 1983 report to the Railways Corporation Board [91]:

*Since colonial days, the government has actively participated in the development and operation of Railways... However, in 1981 Railways status changed... These commercialisation efforts have been largely aimed at enabling the Railways to adapt to the changes around*

*them, becoming more responsive to the customers and acting on a self-sustaining basis.*

From 1981 onwards Railways continued to face further hurdles to its financial viability, the 150 km road limit was done away with in 1983, meaning that transport of freight was open to anyone.

Throughout 1984 a lot of attention was given to a report commissioned by the Corporation, by the United States consultants *Booz, Allen and Hamilton*. They had been engaged to *Review the effectiveness and efficiency of the present operations.*

Throughout the rest of the 80's Railways shed many of its employees (1983: 21,000, 1989: 11,000 [92], and shut down unprofitable lines as it struggled to become once more financially viable. The management structure changed to what were known as *Business Groups* and each was constituted as a profit centre. The *Freight Business Group* took responsibility for rail freight marketing and operations, along with all the former workshops and way and works functions. While the *Passenger Business Group* looked after all passenger services, whether train or bus, a further group took over the management of the Railways' extensive property network.

Thus the structure of Railways was becoming commercially rather than socially minded, staff numbers continued to fall, productivity went up, real freight rates went down and the public perception improved markedly.

The nineties look like a consolidation time for the Railways, with the corporation being down scaled to a transition organisation for the disposal of bus services and excess properties, while the remaining activities were vested into a limited liability company on 28 October 1990. The aim of Railways management now seems to be to focus solely on their *core business* of moving freight and passengers by Rail [93].

Since its beginning the fortunes of Railways have changed many times, the influence of a small, fragile, and often turbulent

economy, and the effect of socially minded government policies over the years, have been instrumental in these changing fortunes.

Going into the 1990's, Railways is faced with a new challenge, for the first time in its history it is effectively unshackled from Government policy, and must now survive in a totally deregulated market. Its survival will be based, to a large extent, on overcoming the prejudices held by the New Zealand public. The general populace of New Zealand has long perceived Railways as an inefficient and ineffective organisation, doing its best **not** to satisfy the customers it was suppose to serve.

What New Zealanders failed to appreciate, was that the Railways they saw, was a result of government intervention in the economy, the level of service being provided being a direct result of the totally regulated transport industry. The Railways of the 90's will need to be dynamic and flexible if it is to succeed, the ability to achieve these requirements is based in sound organisational integration. The following sections will therefore look at the evolution of the Railways structure. To do this Beer's Viable System Model will be used to assess the integrative capabilities of the various organisational structures adopted over the past 20-25 years.

#### **8.4 Railways Pre 1970's**

As discussed in the previous section, the existence of the New Zealand Railways had been essentially as a government utility for the good of the nation. The government had aimed to protect its asset, by way of regulation of the transport industry, and thus the Railways became over staffed and inefficient. This situation was exacerbated by the social policies of successive governments, mainly during the 60's and 70's, when a weaker economy and rising unemployment led them to use government agencies, such as Railways, to soak-up the excesses of unemployed. Throughout this, however, it is clear that Railways never lost sight of its main aim, that being to provide transport for freight and passengers. The Viable System mapping of Railways clearly indicates this aim.

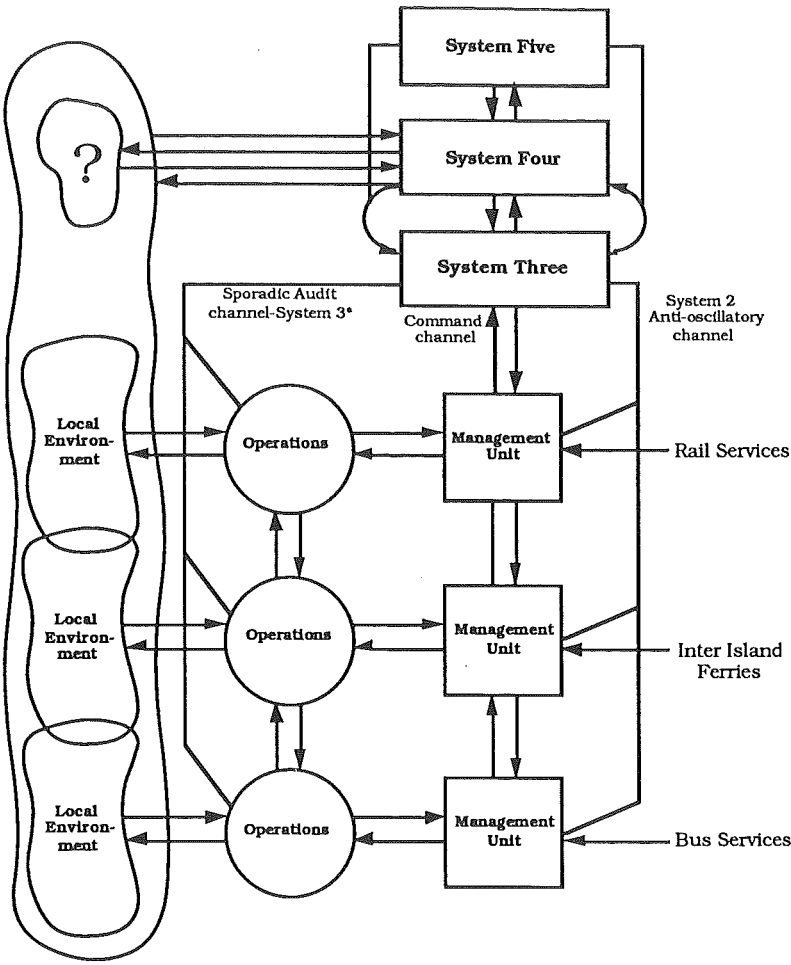


Figure 8.1 Recursion 0 - New Zealand Railways





workshops role within the system, its activities, such as manufacturing, would constitute a part of each of the operational elements i.e. the provision of **new** passenger carriages and wagons for freight. Its role as a maintenance facility would be modelled as a system two activity, within each of the operational elements. Production would also have representation in System Three for activities such as overall workshop management, as well as performing System Four activity for the development of production and maintenance facilities.

Within a structure such as this, with a clearly stateable objective, the possibilities for integration are high, as no conflict should exist between department goals. However, the effect of a regulated transport industry and the use by government of Railways for absorbing unemployment, led to an ineffective System Four, i.e. very little incentive for system development - no competition, and excessively staffed facilities such as maintenance and production. This in turn requiring a very big System Three, at each of the recursive levels, to manage the interaction of the elements - making the management process slow and inflexible. It is a result of this structure, its size and consequent ineffectiveness, that led to the development of adverse attitudes by various groups within Railways, toward such functions as the workshops, attitudes which still exist today. Thus because of its size, the opportunities for integration were largely lost by Railways.

### **8.5 Railways Mid to Late 80's**

It was the passing of the *New Zealand Railways Corporation Act 1981* that reflected the change in governments attitude toward their now unprofitable asset. The Railways were relieved of social responsibility and tasked for the first time ever of providing:

*a return on capital that may be specified from time to time by the Minister of Finance.*

The response was rapid and staff numbers started to fall almost immediately, the emphasis was now on making money. This new direction was given further impetus after the release of the *Booz, Allen and Hamilton* report in 1983/84, with staff numbers falling

by 5,000 in one year. The change in management structure into *Business Groups* further emphasised the commercial direction railways was to take. However, the structure of competing profit centres tied to historical attitudes appears to have destroyed the sense of unity within the corporation, as profit maximising sub-units fought for their individual survival, losing sight of the one time objective of providing transport services.

The following mapping aims to show why this commercialisation detracted from Railways traditional objective, and what problems were likely to exist within such a structure as far as integration between design and production was concerned.

In figure 8.3 all of the units have been established as profit centres and certainly each is capable of becoming viable should it be necessary. However, in searching for a common role for System Four no solution could be found within the realms of the transport industry. In other words **no** common objective could be found for all of the operational elements, there was no unifying objective except the making of money. This is consistent with the profit oriented structure that had been adopted and with the observed behaviour of the system.

Modelled this way the New Zealand Railways Corporation constitutes nothing more than a holding company, with each of its operational elements constituting operating companies. The system therefore exists to make money. With this unifying objective it becomes easy to understand the relationship of elements within the organisation, and the roles of Systems Three and Four for such a diverse company.

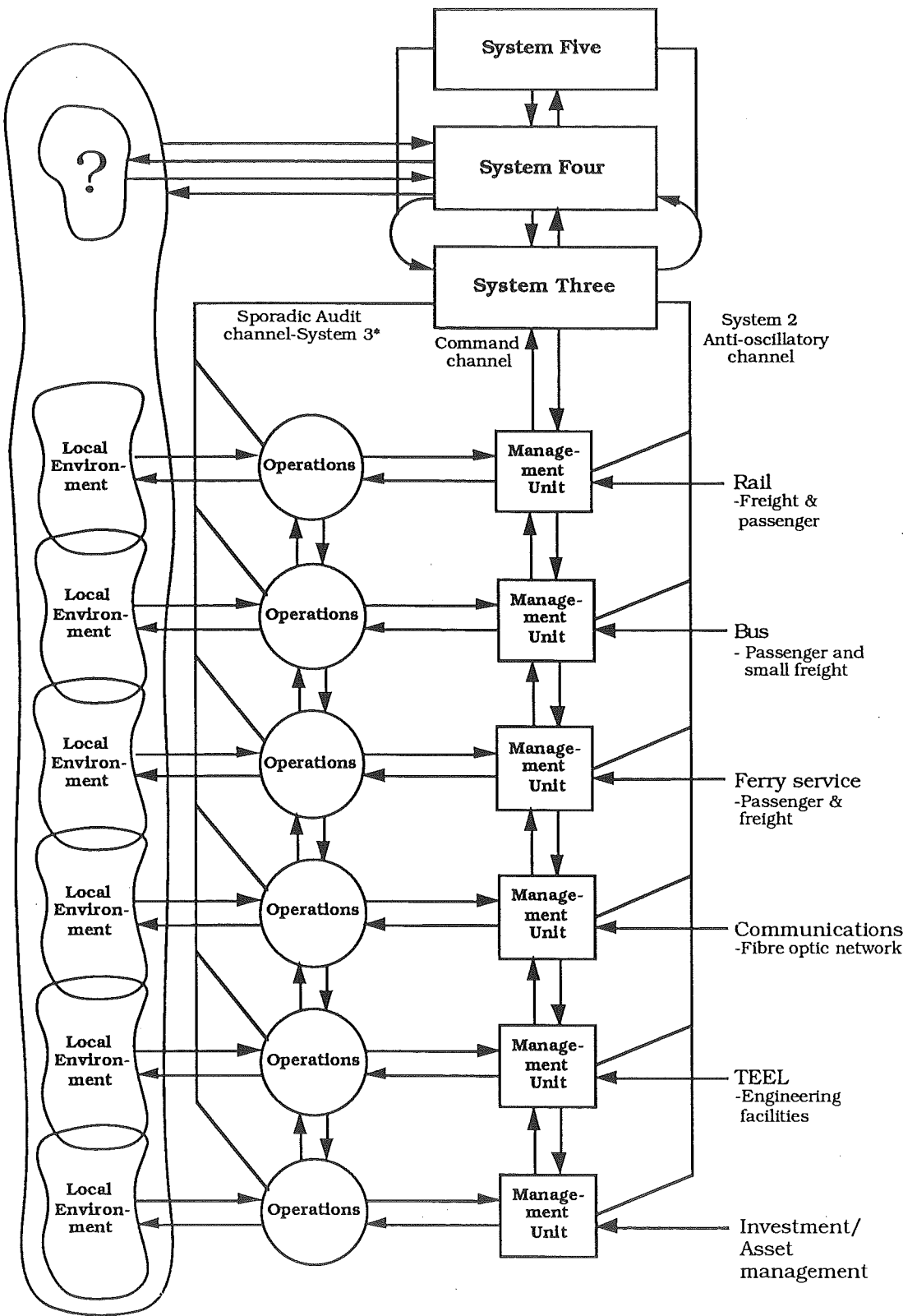


Figure 8.3 Recursion 0 - New Zealand Railways  
Mid to late 1980's

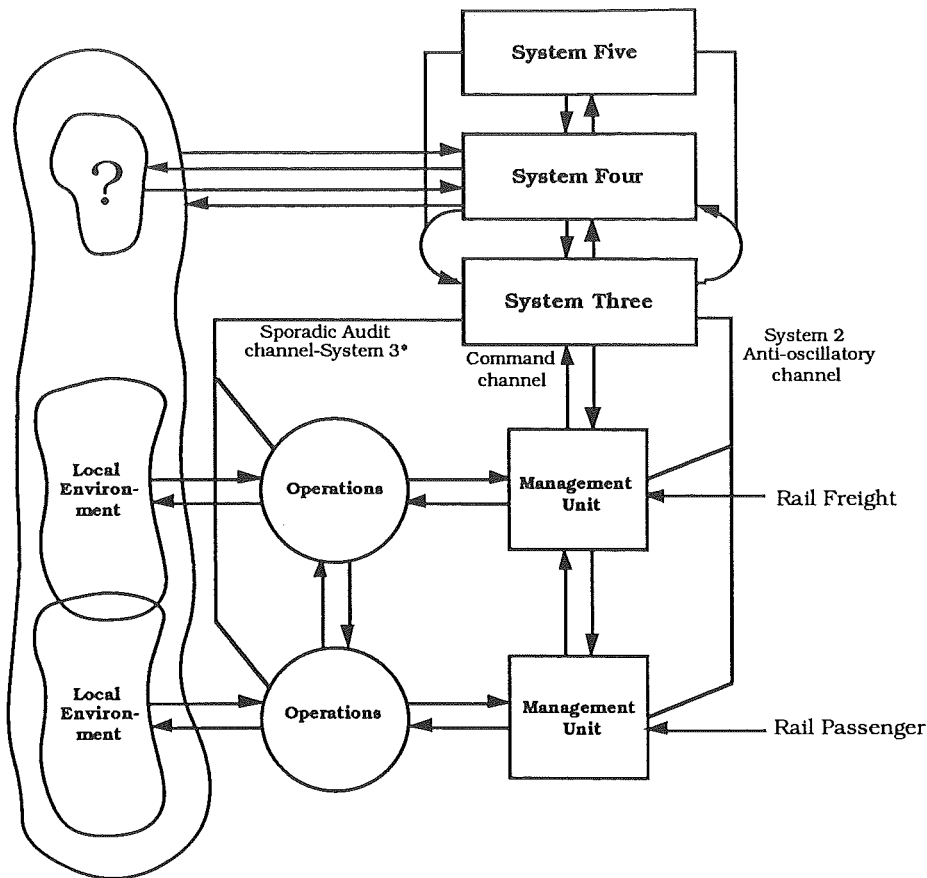


Figure 8.4 Recursion 1 - Rail

Thus the company is integrated on the basis of making money and not on the provision of a transport network. The System Four activity in this case should be looking at the problematic environment in terms of finding new money making opportunities. While the prime role of System 3 would be the allocation of resources, primarily financial, so as to maximise the total return to the corporation. The anti-oscillatory function performed by System 2, would be concentrated toward ensuring that individual profit maximisation did not occur at the expense of the total return to the organisation. This situation did in fact occur within Railways, when one operating company was competing for work outside of Railways, however, it needed reduced transport rates from one of the other elements to be sure of winning the contract. The contract would have netted the Corporation a substantial profit, but because of the need for profit maximisation by all operating companies, the discounted transport was not forthcoming. The result of which was that for the sake of around \$5,000 worth of transport a \$100,000 potential contract was lost

to a competing firm by \$4,000, with a net loss to the railways of many thousands of dollars.

This problem existed because although it operates as a finance company, Railways still sees itself as a rail company, and as such has inappropriate management systems for the way in which it operates in reality. Another problem brought about by the profit maximising structure, is the lack of trust that is building between the various elements. One operational element in particular has a distinctly negative attitude toward another, this attitude essentially results in the business group concerned rejecting the other's abilities based on the years of past dealings prior to restructuring. As a result of this, the affected operational element, which is particularly dependent on the other element, has turned its attention to activities outside of Railways, since it finds the contracts far less one sided, and prefers the feeling of trust that exists during the course of projects, unlike that experienced when carrying out Railways related work.

In terms of technical integration we must refer to figure 8.4, in this recursive dimension resides the rail activities of the corporation and it is at this level that integration for the purpose of providing rail transport emerges. At this level, technical integration is essential, as within System Four of the two operational elements (Recursion 2, Figure 8.5) new designs for wagons and carriages will be generated, to try and tailor the capabilities of the system to the needs of the environment. Production of the new designs also occurs within the elements, and maintenance as part of System 2. However, within the Railways' Structure the ownership of the rail operation and of technical design facilities reside in different operating companies i.e. Rail Freight System and TEEL. Thus the profit maximising activities of each group will (and has) led to significant friction. A result of this is that the companies are integrated (to a limited extent) in a financial sense and almost not at all in a technical sense.



In the following chapter an analysis of a design and production project will be analysed and examples will be given to highlight the problems indicated in this section. The structure used for analysing Railways will be as given in this section because it represents the structure prevailing throughout the collection of data.

Prior to the next chapter, however, an analysis of the new railways structure (implemented 28 October 1990) will be presented.

## **8.6 Railways in the 1990's**

The 28th of October 1990, represents an historic date in the development of the Railways in New Zealand. On this date the previously government owned Railways corporation changed name and became *New Zealand Rail Limited* and 184,900,000 \$1.00 ordinary shares, owned equally by the Ministry of Finance and the Ministry for State Owned Enterprises, were released.

While *New Zealand Rail Limited* was being created, the *New Zealand Railways Corporation* was taking on a new role. In the vesting order generated to enable such a change, the transfer of assets and liabilities to the new company were outlined. Remaining with the old Corporation are the passenger bus services, the Speedlink parcel business and all of Railways' property, from this the new company will lease that property it requires to run its business. The excess properties, bus and parcel services will eventually be sold off by the Railways Corporation. To announce the formation of the new company, advertisements were placed in a number of New Zealand's metropolitan newspapers, such an advertisement is shown in figure 8.6 below.



# **New Zealand Rail**

## **Notice to rail customers and others**

This week a new company, New Zealand Rail Ltd, took over the New Zealand Railways Corporation's rail operation.

New Zealand Rail Ltd is a totally new company, completely separate from the New Zealand Railways Corporation.

The services of New Zealand Rail Ltd include:

- Freight distribution
- Commuter and long-distance passenger services such as the Northerner, Tranz Alpine Express and the commuter trains in Auckland and Wellington
- The Interislander ferries.

The mission of New Zealand Rail Ltd is to:

"Profitably satisfy our customers with quality and competitively-priced freight and passenger services by rail and interisland ships".

Tickets, contracts and so on issued under the former management structure will, of course, be honoured. However, all dealings will now be with New Zealand Rail Ltd, as the holding company for the different business groups within the new railway organisation, namely:

- Railfreight
  - Rail Passenger
    - The Interisland Line
      - TEEL
        - Railnet
          - Raildata
            - Railtel

All property will remain in the ownership of the Corporation and the new company will lease from the Corporation only what it requires to run the business.

The passenger buses and the Speedlink parcel business will also remain with the Corporation.

If you want to make enquiries about the Corporation's remaining businesses please contact them either direct or via their head office - (04) 498-3385.

How will the change affect you, our customers? Our aim is to continually improve the services we provide. The new company will enable us to focus solely on our "core business" of moving freight and passengers by rail. The staff of the new company are committed to providing our customers with the best possible services. If you have any thoughts on how we can improve these please contact either myself or the Rail people you deal with.

Thank you, and welcome to NZ Rail



Francis Small  
Managing Director

 **New Zealand Rail**

Private Bag, Wellington. Telephone (04) 725-599

Figure 9.6 New Zealand Railways Press Release [From 95]

The advertisement indicates that the new company will act as a holding company for the various business groups that constitute it, these it lists as:

- |                            |  |
|----------------------------|--|
| <b>1. Railfreight</b>      | <i>Uses the New Zealand Rail Network to provide rail freight services in such a way as to meet the needs of its customers.</i>       |
| <b>2. Interisland line</b> | <i>Provides a ferry link between the North and South Islands.</i>  |
| <b>3. Rail Passenger</b>   | <i>Operate urban and long haul rail passenger services.</i>  |
| <b>4. Railnet</b>          | <i>Provides the rail network to meet the needs of its rail customers (i.e. Railfreight and Rail Passenger).</i>                      |
| <b>5. TEEL</b>             | <i>Provides engineering construction and maintenance services to New Zealand Rail and markets its skills to a wider client base.</i> |
| <b>6. Raildata</b>         | <i>Responsible for providing information technology solutions to the various business groups.</i>                                    |
| <b>7. Railtec</b>          | <i>Supports the core business by provision of an integrated telecommunications network.</i>  |

All of these business groups have been established as profit centres, although only four of them (1,2,3,4) have any contact outside of New Zealand Rail, the others making their profits by transfer pricing. On top of these business groups New Zealand Rail also retains a number of investments and shareholdings.

The new company has a corporate mission statement, which states that the mission of New Zealand Rail is to:

*Profitably satisfy our customers with quality and competitively-priced freight and passenger services by rail and interisland ship.*

Within the corporate mission statement exists seven separate statements, one each for each of the business groups. Except in the case of Railfreight Systems and Rail Passenger, each of the mission statements emphasises that the businesses exist to provide a *cost effective* service to ensure the profitability of the core business. Thus it appears that inter group profit making has been de-emphasised in favour of support for the business of rail transport.

Difficulties may arise in the future, however, as although such groups as Railtec are established as a profit centre, other business groups are unable to go to competing communications companies if dissatisfied with the transfer prices, or the service received. Additionally, the notion of being profit centres may encourage some of the business groups to embark in non-railway activities in the future, if the transfer prices are set at a level which does not allow a satisfactory profit to be made. This would have the effect of generating additional operational elements within the company and thus place burden on the resources available to the core business activities.

Under the new structure therefore New Zealand Rail has been modelled as figures 8.7, 8.8 and 8.9.

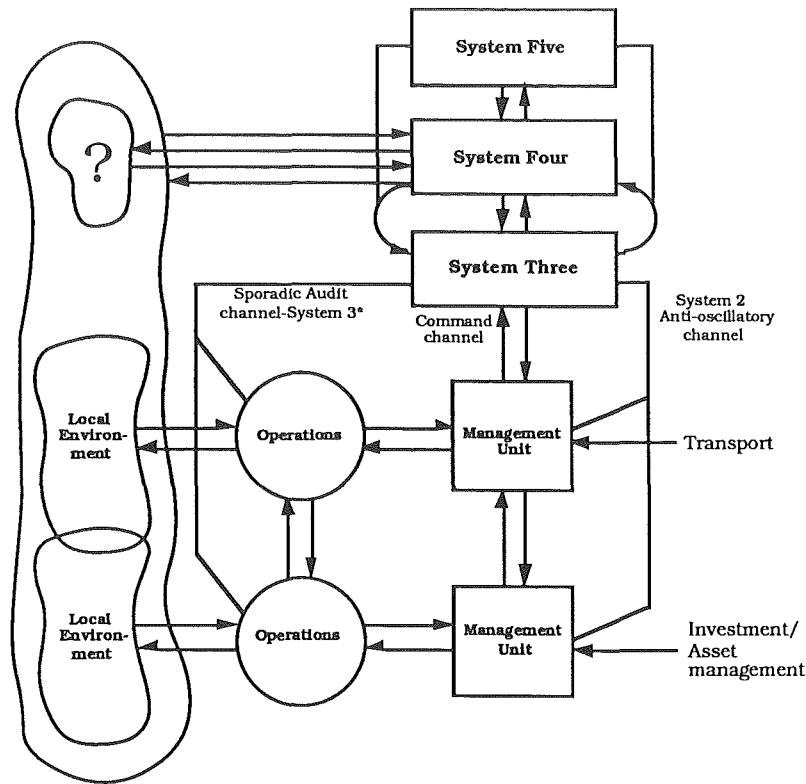


Figure 8.7 Recursion 0 - New Zealand Rail

This level of recursion exists purely for the generation of wealth, with System Four looking for financial opportunities to enhance the return to the company, and System Three looking after allocation of financial resources. In the case of New Zealand Rail the transport recursion is significantly larger than the Investment/Asset management recursion.

The transport recursion (Recursion 1) exists to satisfy the transport requirements of its customers and potential customers. System Four in this case would therefore be looking at new opportunities for the organisation e.g. by the addition of a bus network for instance, or looking at ways at enhancing the network to tap previously untapped markets.

In the case of Recursion 1 the investment in the Rail Transport network is far larger than that in the Interisland line.

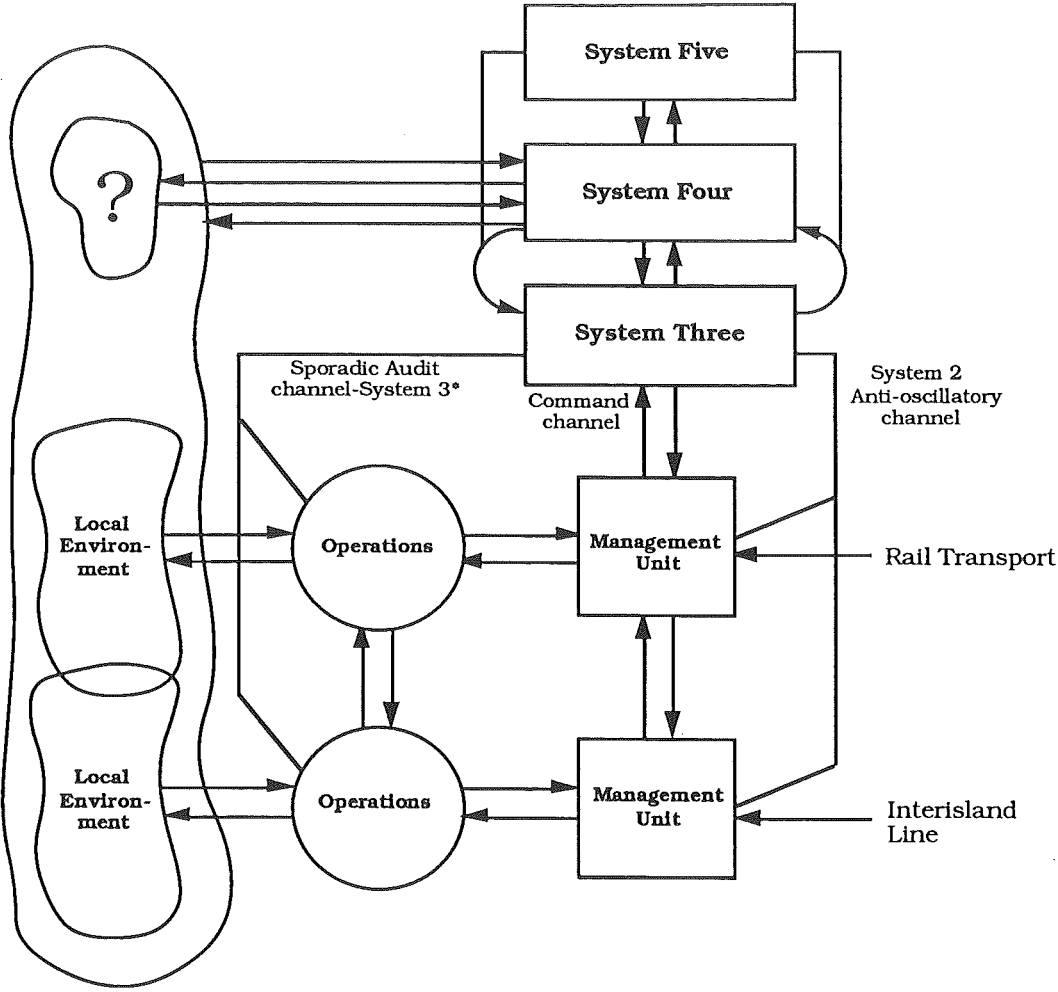


Figure 8.8 Recursion 1 - Transport

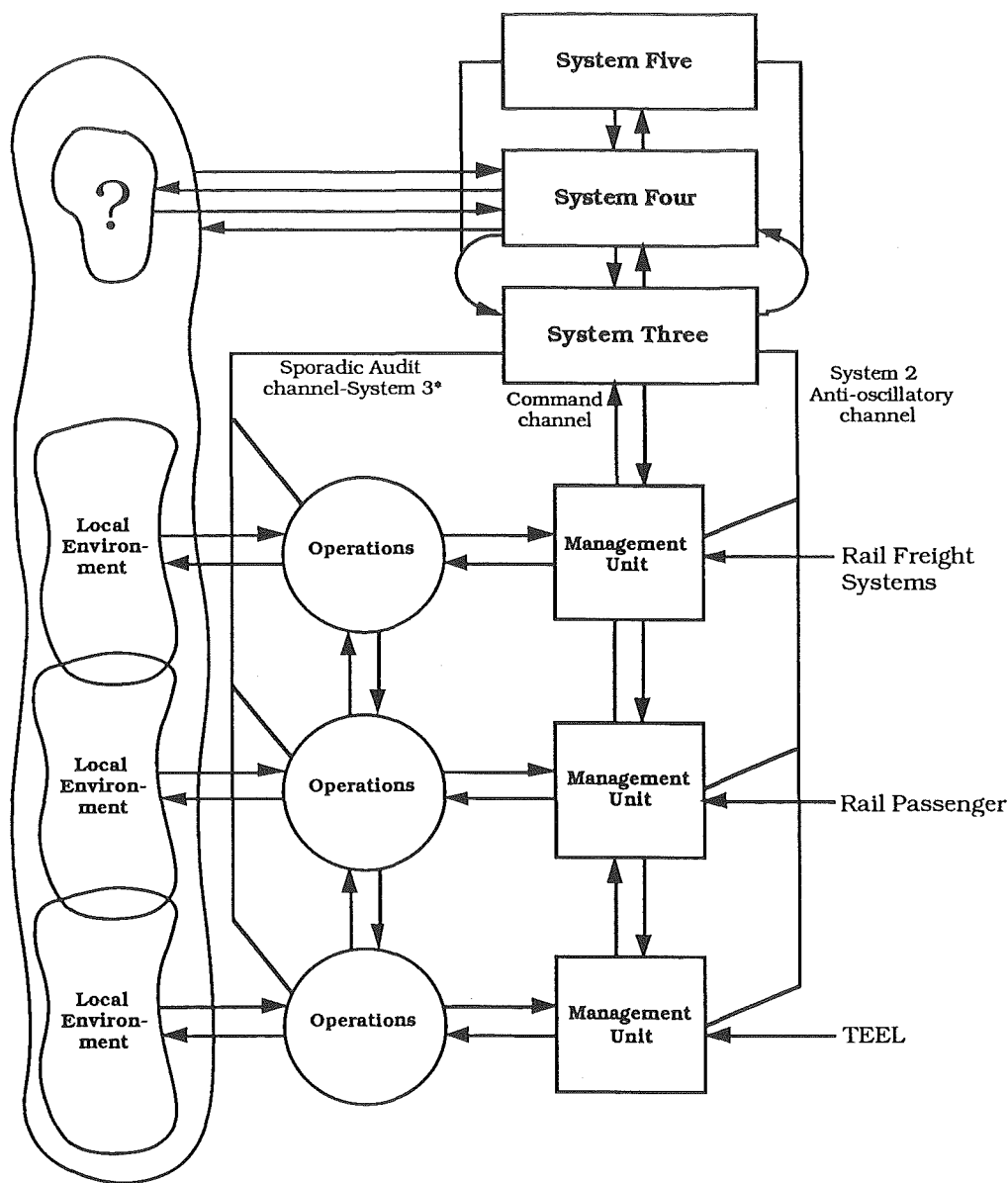


Figure 8.9 Recursion 2 - Rail Transport

Obviously the Rail Transport recursion, exists to provide rail services to satisfy the demand in the environment. Included at this level is the technical services needed to implement the commercial decisions, such as building new wagons and carriages so as to take advantage of new or developing markets, as seen by the marketing arms of the two other operational elements.

Technical integration is obviously important to this particular level of recursion, as its viability is dependent upon its technical investment. However, it is the next lower level of recursion in which the design and production facilities exist functionally. To

show this the dominant operational element will be detailed, that being Rail Freight Systems.

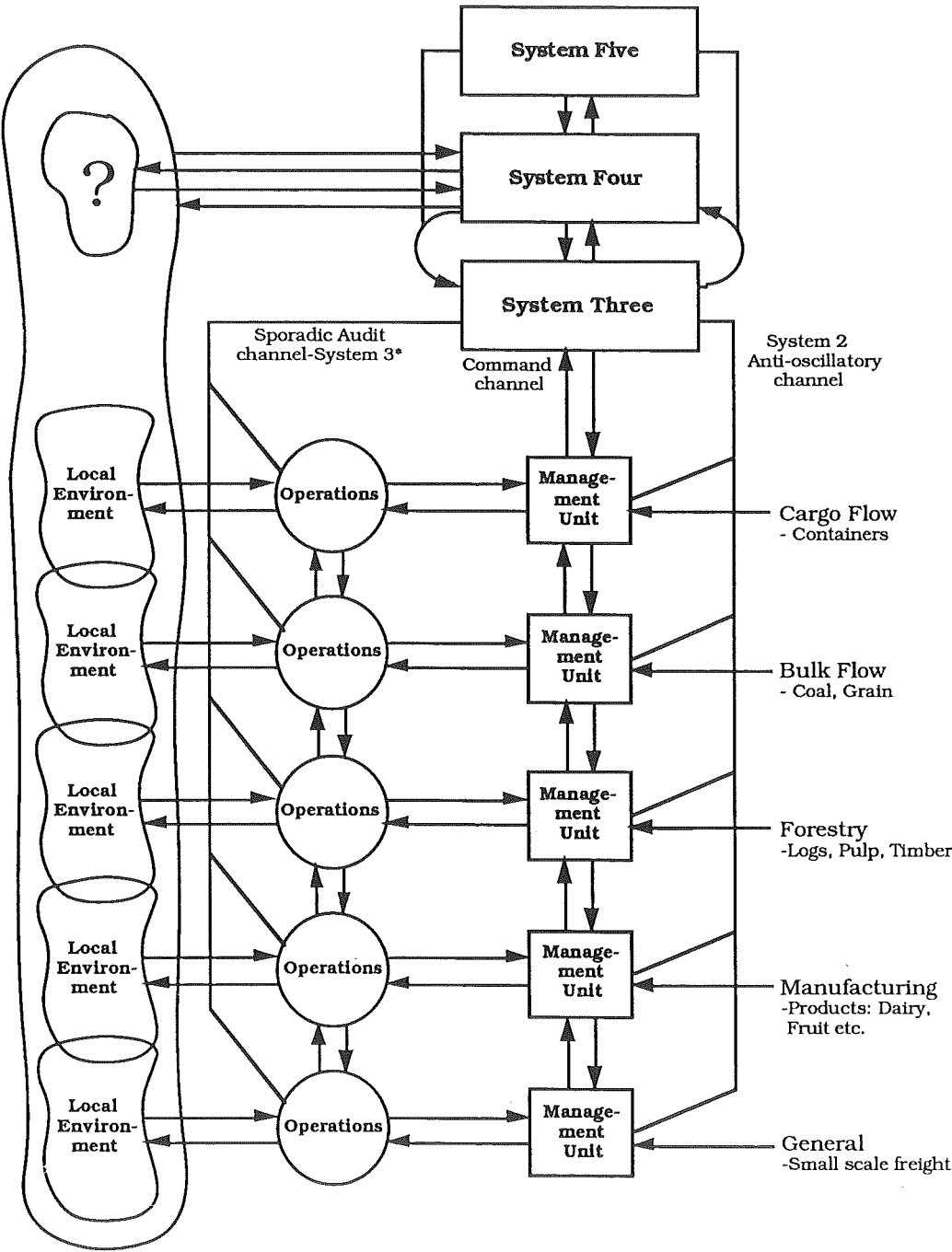


Figure 8.10 Recursion 3 - Rail Freight Systems

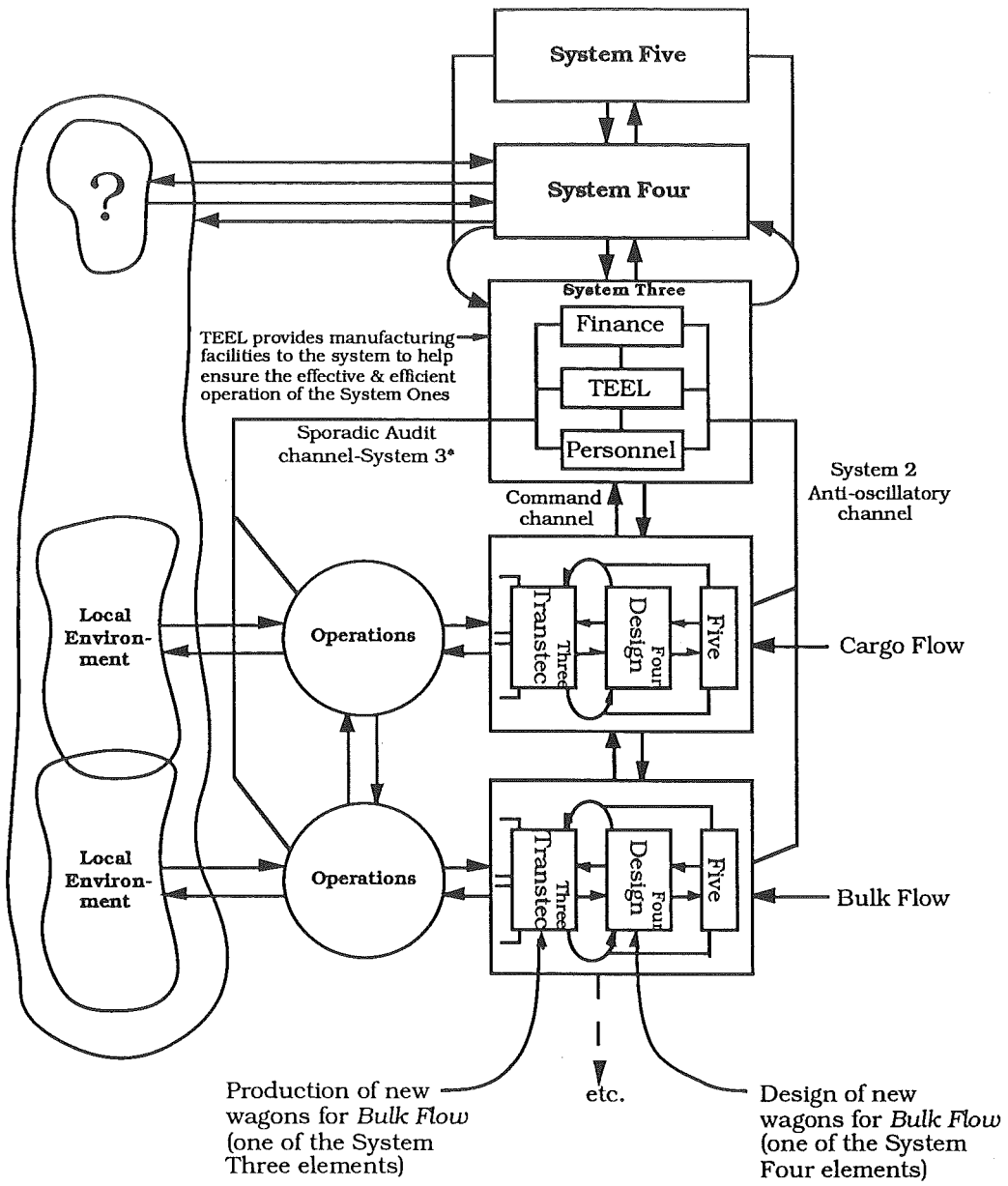


Figure 8.11 Recursion 3 - Expanded Detail



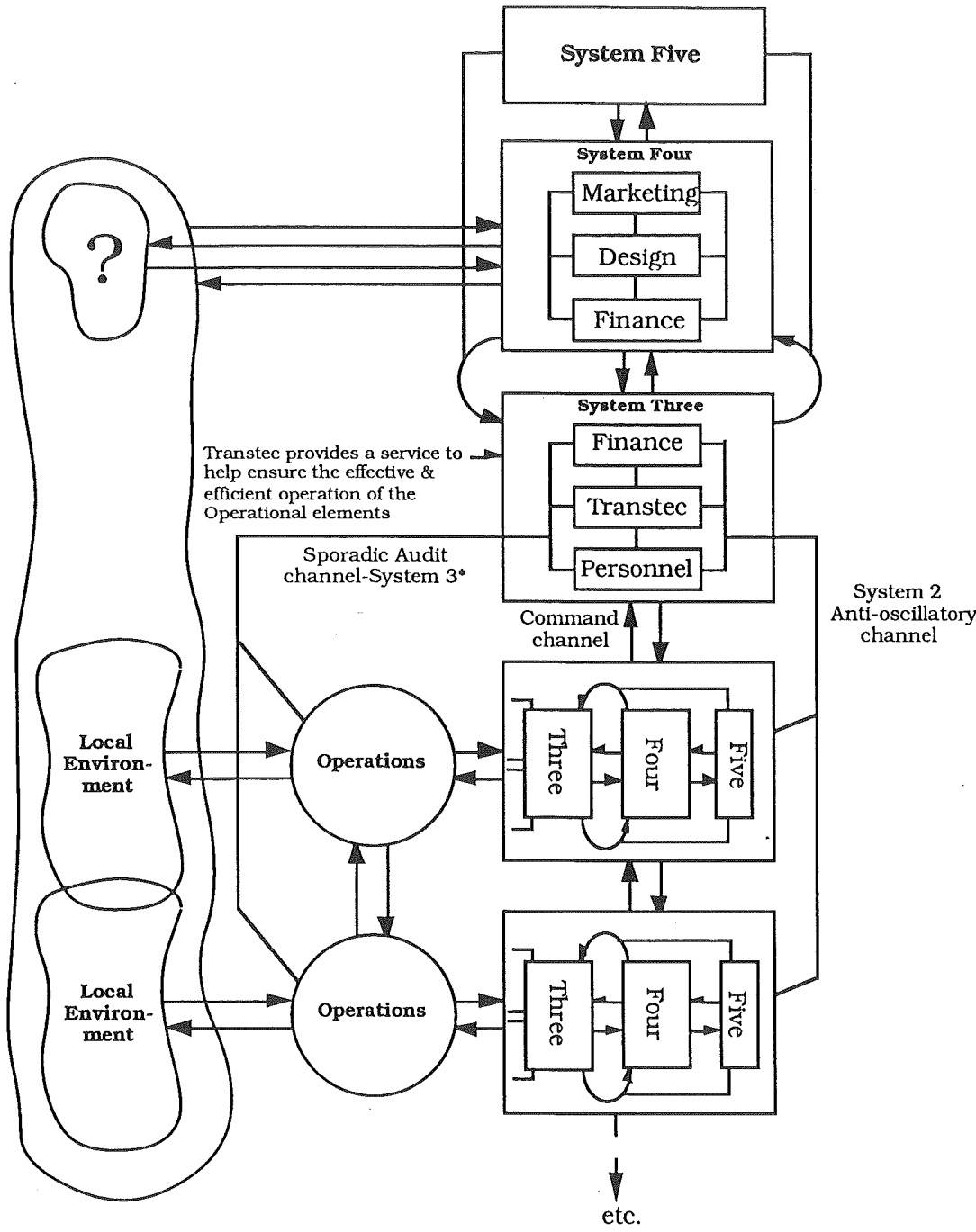


Figure 8.12 Recursion 4 - A Market Segment

The present arrangement within Railways requires that if some element of Rail Freight wants a new design built, it must first approach Rail Freight management, in turn this must approach System Three of Rail Transport for the allocation of resources i.e. finance so as to pay for the new wagons etc. Rail Freight Systems then has to communicate with the TEEL element which in turn

communicates with a Transtec office to arrange construction of the new design.

Designers are actually working in System Four of recursion 4 e.g. Bulkflow, where they are specialised in that particular field. Production is operating in the management subsystems System Three's of Recursion 4 in the same way finance or personnel does, its role now is to provide a service to the System 1's, to help ensure their effective and efficient operation. In this way the production elements are subservient to the needs of the wider system. In this form TEEL/Transtec can not be profit centres but must be cost centres.

An alternative structure if it is desired for production to interface with the wider environment is that TEEL be another operational element of Railfreight systems, see figure 8.13.

In this way TEEL can still do outside work and earn money for the system, but now the production of wagons etc. would be based on a system of transfer pricing. If an operational element found the transfer pricing too high, and it wanted to go into the environment to get wagons made, it would have to ask System Three. System Three which has a wider picture would say yes or no, for example it may prefer to subsidise the TEEL quote simply to maintain the manufacturing infrastructure.

Under the present structure, the production elements are being managed at the wrong recursive level for the function they perform. Thus the systemic requirements for manufacturing elements is not obvious, and the profit orientation does nothing to improve the situation. By disposing of the production elements it will allow the individual units to interact directly with the environment, and employ production facilities outside of railways. This is adequate while the engineering industry is depressed, but if the New Zealand economy does recover, then it may be very difficult to employ production facilities at will, and within cost constraints.



need to be added within their system 4's thus allowing the market demands to be developed into a technical embodiment.

The production facilities, to produce the new designs, will reside (functionally speaking) within the System 3's of these new operational elements. Previously it was stated that the technical facilities i.e. TEEL, resided at recursion 2 (Figure 8.9), however, TEEL consists of four branches known as Transtec offices. In an aim to stop competition of the various Transtecs, TEEL has made each one of them responsible for the production of different types of wagons, in this way the Transtec offices are functionally integrated into one or more of the recursion 3 operational elements.

Technical integration is essential to this recursive level as the ability to respond rapidly to market requirements is obvious, if it is to survive in an unregulated transport market. Technical integration will help ensure that the best design for the job is generated, and is produced at the lowest cost to the organisation, in a length of time consistent with the needs of all participants, i.e. marketing, purchasing, production etc.

Severe difficulties could well exist if the goals of the production facility are not consistent with that of the rail system, or if the system of transfer pricing causes friction between the two groups. With the production elements being able to deal with *external* customers, it may well choose to do so in preference to Railways work if it finds that work more rewarding and commercially acceptable. This is a situation that may well arise with TEEL's intended role being to *Market similar services (to those provided internally to New Zealand Rail) to a wider client base.*

The young age of New Zealand Rail precludes any analysis of whether technical integration will face difficulties, but the structure as it exists, with its profit orientation does little to encourage close ties between design and production.

The following chapter looks at a product designed within Railfreight Systems design office, and produced by the Transtec office in Christchurch prior to the October 1990 changes. The

purposeful design model will be used to interpret difficulties or problems encountered with the product and the relationship between technical integration and organisational structure will be discussed.

## CHAPTER 9

### DESIGN AND DEVELOPMENT OF THE GST CONTAINER

#### 9.1 Introduction

The GST container (refer to appendix C for New Zealand Railways description). was built by Railways as a low cost high capacity container, for the transport of a wide range of palletised stock and 2.4 m x 1.2 m boards, e.g. Jib and particle boards. GST is an abbreviation of the containers Railways description (G)eneral (S)ide (T)autliner, meaning that it is loaded from the side, with the door being of a stretched curtain type construction (see figure 9.1).

The design of the container was the result of two distinct events, the first of these being a query from a senior Railways manager, on the need to stick to ISO wagon sizes. The second being a problem encountered by one of Railways' customers, concerning the inability to load existing containers to their full capacity, because the containers were slightly too small to take 12 goods pallets, thus resulting in wasted space.



Figure 9.1 The GST Container

The designer involved saw the possibility for an improved container design and after investigating the abilities of trucking companies (the GST container is intended for loading at the customer's depot, transport by truck to a Rail yard and then transport by rail and truck to final destination) to handle larger than standard containers, proposed the design of a non standard goods container. The need for additional containers was well known within Railways and shortly there after funds were approved and detailed designing got under way.

Initially a prototype was constructed by the Dunedin Transtec office and was trialled for some nine months. As a result of these trials several difficulties were discovered, resulting in changes being made to the design. At this stage a contract for 70 containers was let to the nominated container maker within Railways, the Christchurch Transtec office, and production commenced. After the initial containers were completed they were toured around New Zealand, showing sales and marketing personnel how they could be loaded and unloaded. This type of demonstration was also put on for various potential users of the product.

Almost immediately problems were encountered with the containers, resulting in withdrawal from service and subsequent modification. The more significant problems included; an inability to lock the curtain type doors, making the container unattractive to some customers; water leakage into the interior, resulting in damage to stock; and an inability to load certain goods, such as pallets of casked wine. Other problems were encountered during manufacture, and while not affecting the performance of the product, they certainly affected the ease with which they were constructed and thus the manufacturing costs.

These problems and difficulties, will now be discussed in terms of the Purposeful Design Model (PDM). In gathering the information for this analysis, a wide cross-section of people were interviewed, ranging from the designer and draftsman, through to the production workers and factory managers. Before commencing with the analysis of the GST project, it is worth noting that the

design is of a fairly simple nature, thus a lot of the problems associated with the design are minor. It should also be noted, that the designer involved in this project is young and very talented, with a very good innate sense of what should be considered when designing a new product. It is his abilities which have resulted in a rather more integrated<sup>1</sup> design than is usual for the Railways' mechanical engineering design office. This is not only an observation made by the researcher, it is a widely recognised attribute by many of those involved, particularly by Transtec's production and management personnel.

**9.2 A purposeful Description of the GST Container Project**

In analysing this project a significant quantity of data had to be assimilated, to do this it was necessary to distinguish clearly between the various recursive levels of the project. The GST project will therefore be modelled as three recursive levels. These levels are as indicated in figure 9.2 and the purposeful designer in each case is also indicated.

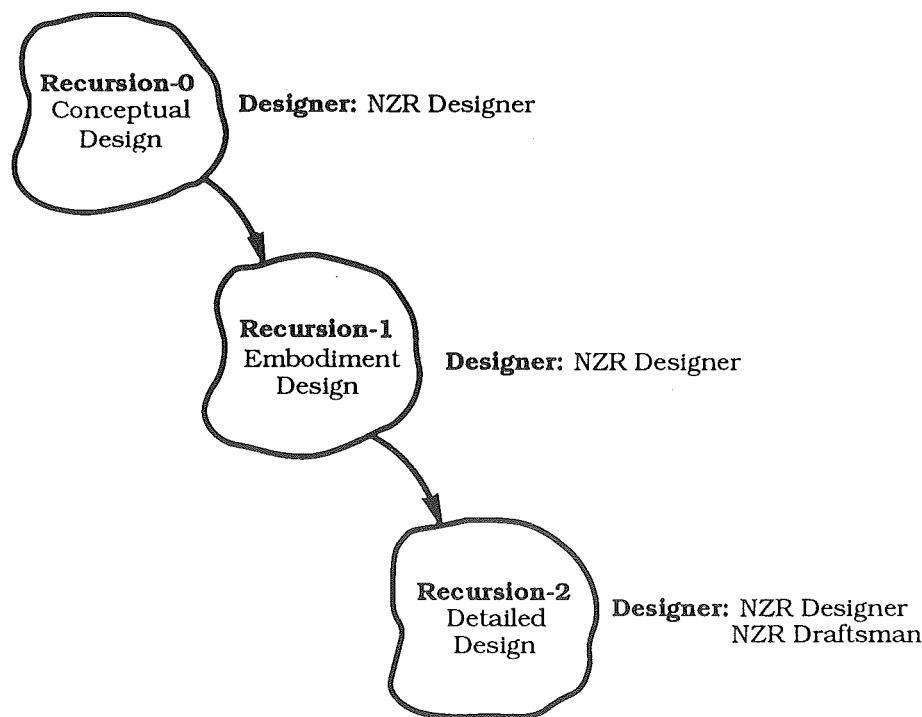


Figure 9.2 Recursive Levels of the GST Project

<sup>1</sup> The term *Integrated* relates to the extent to which the requirements of all those affected are incorporated.



The reasons for specifying the recursive levels in this way, is that the design of the new container was very simple. Thus only a single recursive dimension exists, with the major design steps representing the only logical division of recursive levels.

- a) **Conceptual Design:** *The designer at this level is required to integrate the requirements of the client, with the capabilities and requirements of Railways, thus specific technical considerations are not likely in the design activity.*
- b) **Embodiment Design:** *Here the designer must take the next level designer's objective, and develop it into a broad technical solution such that the higher needs are satisfied. Technical considerations from this level may influence the beliefs of the higher level designer about the properties the design should contain.*
- c) **Detailed Design:** *This level of recursion **may** be comprised of a number of recursive dimensions, and is the level where the broad technical solution is developed to the point where production of the artifact can commence. As with the embodiment level feedback from this level may modify the higher level designer's objective.*

The meanings associated with these three headings are those used by Pahl and Beitz [28].

### 9.2.1 Recursion 0 - Conceptual Design

This level of design is largely organisationally oriented, and as such is concerned with the conceptual design of a new product to be consistent with the companies needs and stated organisational objectives. In this instance it was known that Railways required at least 70 more containers to meet the needs of its customers.

### (a) *Designer - Client Interaction*

The GST container was the result of two unrelated interactions with the designer, firstly by a senior Railways' manager and secondly a Railways' customer, via a freight sales representative. The designer-client interaction is one in which the information needed to define a potential product is gathered. As such it is essential that the designer be intimately familiar with the needs of the client, his belief about those needs must be clear and complete.

In developing the system specification for the GST container, the designer visited the customer, who had made representation to the sales representative regarding problems experienced in loading conventional containers. The interaction undertaken by the designer, highlighted the fact that the container was slightly too small to enable all its available space to be utilised when loading palletised goods, or 2.4 x 1.2 m boards, see figure 9.3.

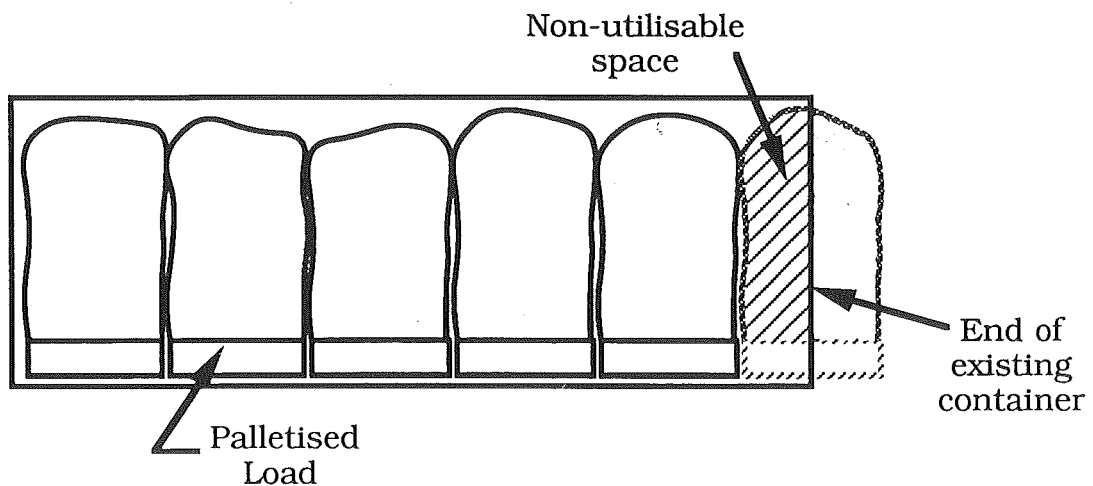


Figure 9.3 Existing Container Design

Because of the non-utilisable space within the old containers, it was generally necessary to fill the remaining space with some form of packing, thus ensuring that the load within the container was secure, and therefore not subject to damaging movement while in transit.

By interacting with the client directly, and by having a clear knowledge of the function of containers, as a transport medium, the designer was able to develop a very clear belief about what structural and functional properties the client saw as important. This observation is supported by the universal acceptance and demand for the new containers.

***(b) Designer - Co-Designer Interaction***

The co-designer would traditionally be an assistant to the designer, in the Purposeful Design Model, however, the co-designer is the designers alter-ego. It is essential that the co-designer works at the same level of abstraction as the designer, in this way if there were to be an untimely departure of the designer, there is someone to take his place immediately. The co-designer would also share the same beliefs about the solution as the designer, and thus an expensive and time consuming redirection in the project would be avoided.

The GST project was typical of Railways' projects and as such no co-designer type role existed. As the designer stated;

*Had I been run over during the course of the project, it would have caused a serious disruption to the project, as no one would have had any idea of all the requirements of the design.*

It was also considered likely by the designer, that any one picking up the pieces of his project, might also adopt a quite different approach to solving the problem. The appointment of a full time co-designer to a project of this scale is obviously unnecessary, but to overcome the inherent problem of not performing this role, it would not be difficult to involve a designer from another project from time to time, especially when formulating the solution concepts.

*(c) Designer - Functional Expert Interaction*

The designer's beliefs about where the organisation is going and what its capabilities are, will more often than not be limited to a what he has heard others talking about, or discussions he may have had. To ensure that his beliefs about the organisation are adequate, before committing the organisation to a project, the designer must involve all of the sections likely to be affected by the development of a new product. Marketing is an obvious example. While it is likely that product ideas will have come into the organisation via marketing, it is not necessarily the case, the GST was such an example, where the product description was developed by the designer. In the case of marketing it is important that the declared business strategy adhered to, and that any new product fits within it.

In the case of the GST project, it was known that containers were a favoured form of transport by many customers, because of their transportability on road and rail, and that a need existed for some 70 additional units. Thus it was marketing's belief that the eventual design should be attractive to a wide range of clients.

At this point the issue of container security should have become obvious, and the designer's beliefs about required structural and functional properties, modified to include some way of securing the curtain doors. Although eventually remedied (see figure 9.4), the security issue resulted in several customers initially rejecting the GST as a suitable means of transporting their goods.

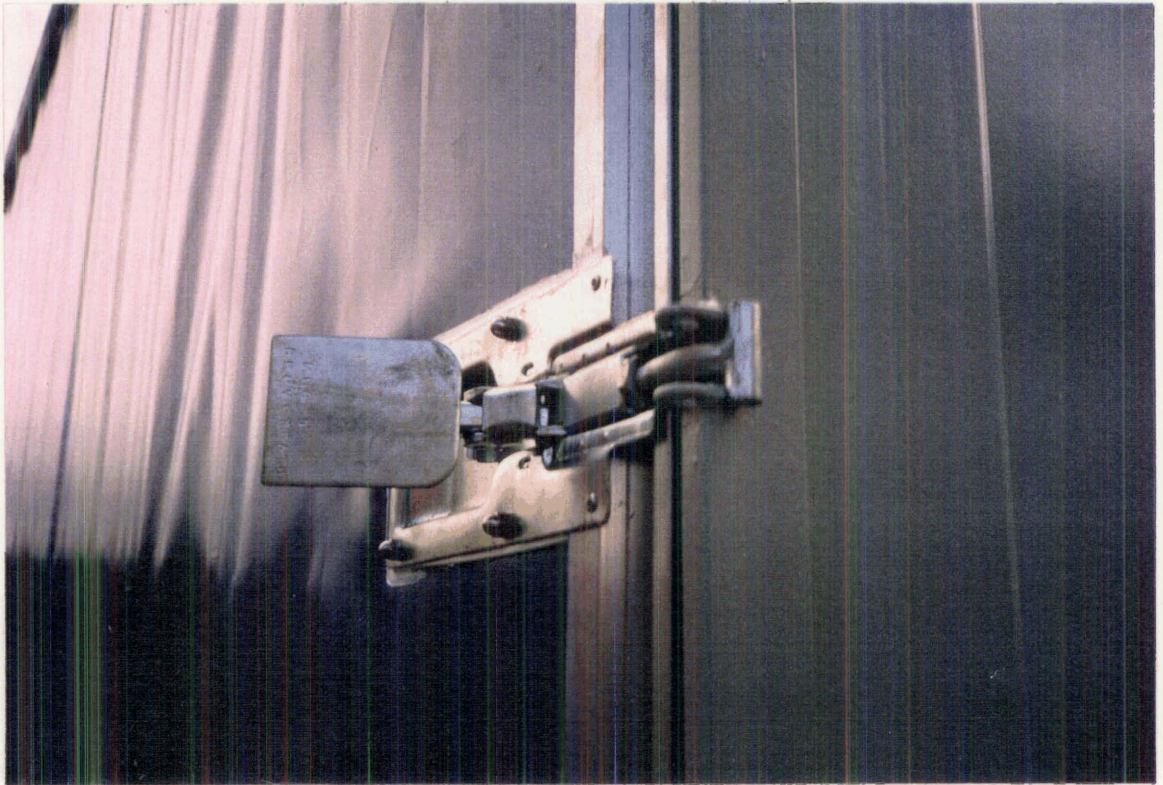


Figure 9.4 Door Securing Mechanism

It is this type of problem that can lead to the failure of a new product, whether it be the outright rejection of the product in the market place, or the need to recall those units all ready released for modification, and thus making them acceptable. In the case of the GST container both situations occurred, luckily the fault was detected at a very early stage. It was an inadequate set of beliefs that brought about this situation. The initial client contacted may not have required a lockable container, however, the need to make the container acceptable to a wider client base, and thus satisfy organisational objectives, should have resulted in a wider set of possible users being approached, regarding their requirements. The ability to finance the proposed programme was also considered during the concept stage, by making application to Railways group management for funds to design and build the proposed container.

The financial situation is another important aspect to consider when developing a new product, as the financial resources of the company will be changing from month to month. If the GST

container had been a more capital intensive project, then Railways may have had to look at financing arrangements etc. It is only by developing a belief about the financial situation of the company, that it can determine what effect the financial outlay will have on the viability of the organisation and when, if at all, the project can proceed.

In the case of the GST project, the sums of money being considered were relatively small, and thus did not pose a threat to Railways' financial viability. In developing a new product, production aspects are also an important consideration to take account of. For instance, the capacity of the plant must be considered, new technologies may now be available, a new and expensive machine may be under utilised, all of these are important factors requiring some consideration in the design process.

With the GST project, production considerations were not considered. For instance, the Transtec office would like a three month planning period, allowing them to organise their production schedule, order raw materials and basically prepare for the up coming production. In general, however, the planning period given is no more than three weeks and often less.

The belief held by those involved in design and marketing (based in Wellington) is that *Transtec (Christchurch) is just another production facility*. As a result there appears to be resentment about being *tied* to the workshops, and a preference to deal with private enterprise workshops, rather than those of Railways. This is definitely an attitude based on the performance of the workshops prior to the reorganisation. The attitude appears to be emphasised by the profit centre structure of Railways. Transtec and the design office reside in different profit centres, and thus the attitude of inefficiency directed toward the Transtec Office, combined with the profit maximising structure of Railways', has effectively ensured that no production aspects are considered at the conceptual design stage.



The aim of the Designer-Client and the Designer-Functional expert interactions is to integrate the needs of the client with the objectives and capabilities of the organisation. In the case of the GST project, the client was generally well served, as were those organisational functions concerned that reside within the same profit centre as the design office. Production on the other hand was not.

#### ***(d) Designer - Belief Expander Interaction***

The belief expander role is intended to stimulate the designers thought processes, so as to give him ideas on how the problem could be solved, this commonly takes the form as such practices as *Brain Storming*.

At the conceptual level of a project the Designer-Belief expander interaction will concentrate on possible general structural solutions to the identified functional and structural properties e.g. alternative construction methods and materials.

Within Railways belief expansion generally takes the form of, reference to international rail and transport magazines, and *Brain Storming* amongst a group within the design office. In the case of the GST, the idea of using curtain sides on the containers, came directly from the use of such doors on trucks.

At a conceptual stage for such a simple product, it is difficult to envisage too many alternative solutions to those finally embodied, therefore it is likely that the Design-Belief expander process was conducted quite adequately.

#### ***(e) Designer - Critic Interaction***

The role of the design critic is to act as a *devils advocate* for the designer in his or her specialist area, such as marketing, finance, production, vibrations, tribology etc. The critic is aware of what the designer is trying to achieve i.e. the selected set of Structural and Functional properties, and is made aware, by the designer, of how he intends to satisfy the clients needs and wants. The critic

then acting within his specialist role, will not agree with the designer's choice of a hypothesis, but rather point out under what conditions the designer's solution will be inadequate. The critic, as part of his task, will also set about designing a testing program to demonstrate to the designer the failure modes that he has determined. It then becomes the responsibility of the designer to integrate the beliefs of the critic back into the design, further iterations will occur until such a time that the modes of *failure* indicated by the critic no longer concerns the designer.

In the case of the GST project, a critic in the marketing area should have detected the fact that the container, as designed, would not appeal to certain customers, as a result of the inability to ensure the security of the container's contents. The designer would then have to consider this assessment, and decide whether this would therefore violate some of the project's aims: in this project it obviously would have. An alternative or additional step that the designer could have taken, would have been to use potential customers in the role of the marketing critic. The advantage of doing this, is that if there were any misunderstanding in the initial problem formulation, it would be detected and thus changes could be made before committing additional resources.

A technical consideration that could have been raised at the concept stage was the issue of employing curtain type doors, while trying to achieve a water tight compartment. A critic in this role could have made this aspect of the design an issue, and developed a testing program to prove his doubts. As it was, water damage to container contents was a problem with early production models. This situation arose even though each container was subjected to a leak test. As one of the production staff commented,

*The testing program for water leaks was inadequate to simulate actual conditions.*

Had a negative approach been taken to the testing of the container, a far more rigorous test would surely have been developed.



### ***(f) Designer - Sub-Designer Interaction***

The purposeful design model, as stated previously, is a recursive model, therefore, a key to its success lies in the integration of designers from one level to the next. That integration is based on two things, the first of these is that the higher level designer must have an accurate belief about the capabilities of the lower level designer. He must know for example that the sub-designer has the correct training and skills to perform the job that he is to be assigned. The second key to the inter level integration, is based on the higher level designer being able to convey fully his set of beliefs about what is required, in terms of a subset of structural and functional properties, to the lower level designer. In this way the interaction between the two designers is essentially a Designer-Client interaction, where the higher level designer is the client to the lower level designer.

The GST project, as with most small projects, suffered no difficulties in this area, since the designer at the conceptual level and the designer at the embodiment level were the same purposeful individual. In this case therefore the beliefs between the two levels were perfectly integrated.

### ***(g) Designer - Design Hypothesis Freezer***

The role of the Design Hypothesis Freezer is to determine at what point the designer should stop any further refinement of his design hypothesis. It is essential that the decision to freeze a design is not left solely to the designer, as in most instances he is likely to be too involved in the project to see that further development will result in a wasted effort.

In the case of Railways, the freezing of designs is left to the individual designers, however, at times pressure is applied from the design office management to finish the project. In the case of the GST project no such pressure was applied, and thus it was the designer's decision on when the hypothesis development should be frozen.

### ***(h) Designer - Documentor Interaction***

A documentor is a person who categorises and documents information for storage and subsequent retrieval. Within the product development environment a documentor would be responsible for documenting information, in such a way as to make it useful to people outside the design recursions. This documentation may take the form of; developing bills of material, for use by production; and the development of manuals, for those involved in such activities as installation, operation, maintenance etc. In this way the documentor is taking sub-sets of the designers beliefs, about what is required to satisfy the desired objective, and is transforming the intention of the designer, into a form suitable for use by an individual with a totally different set of beliefs e.g. the production of a maintenance manual, for use by maintenance personnel. The documentor would also be responsible for the categorising design information, e.g. design classification and coding, for retrieval and use in future projects.

### ***(i) Designer - Administrator Interaction***

The purposeful designer is the key integrator at each level of recursion. It is his role to obtain the views of a group of specialised individuals, and integrate their divergent beliefs in a way in which he feels will satisfy the objectives of the project, and all those concerned. The task of integrating all the views will be a full time one and will require all the training and experience of a specialist individual. He should, therefore, have a highly developed set of beliefs in (depending on the recursive level) the area of engineering design.

To ask the designer to also have a highly developed set of beliefs in the area of organisational administration, is therefore asking him to direct efforts away from designing. The role of administrator is therefore designed to relieve the designer of day to day administrative tasks, and thus allow him to concentrate on hypothesis development. The administrator would be a specialist in the *ways* of the organisation, he would therefore interpret the information flows to him, from the designer or organisation,

within his beliefs about the sender, and transform it into a form of communication appropriate to the beliefs of the receiver.

Additionally the administrator is responsible for coordinating the activities of the designer with the client, functional expert, belief expanders etc., if these roles are performed by people other than the designer.

In the case of Railways, all administrative tasks are undertaken by the designer concerned. The act of looking after the *paper work* was seen as a *bit of a burden* by the designer, and a hindrance to the progress of the design. However, often it was possible to push it aside and catch up with it all at the end of the project.

The Railways' design office is relatively small, therefore, the addition of an administrator for each project would seem beyond requirements, but one administrator could serve a large number of designers, allowing the designers more time to concentrate on developing more integrated designs, and raising their overall productivity.

The conceptual design level of the GST project was generally well done, with the views of a number of people being integrated into the final concept. However, as has been stated previously, the reason for overall success at this level, is that most of the input required was attainable within Railfreight Systems, the commercial freight arm of Railways, and the Business Group within which the mechanical design office resides. Where interactions have not taken place, and thus a fully integrated set of beliefs not attained, it is clear that the reasons lie in the profit oriented structure of Railways, and a long established attitude toward the parties concerned. The embodiment recursion of the project will now be considered.

### **9.2.2 Recursion 1 - Embodiment Design**

Embodiment design is the development of the conceptual solution into a broad technical one. As Pahl and Beitz [28] put it:

*Embodiment design is that part of the design process in which, starting from the concept of a technical product,*

*the design is developed, in accordance with technical and economic criteria and in the light of further information, to the point where subsequent detail design can lead directly to production.*

In the case of the GST container, project embodiment design has been modelled as the second recursive level and consists of just one recursive dimension, thus indicating the simplicity of the project.

#### **(a) Designer - Client Interaction**

In general it would be the purposeful designer at the highest level of recursion, who would interact with a client or client group. However, it may well be conceivable, that a lower level designer may in fact undertake an interaction of this kind, to clarify some point which does not affect the overall conceptual design, performed at the higher level.

In the case of the GST project, determination of such properties as minimum door opening dimensions would constitute such a situation. The conceptual design would have been to make the container large enough to hold 24 pallets, stacked two high and two deep. The embodiment design decision would have been to determine the minimum dimensions required by the client to achieve easy loading of this number of pallets.

If the embodiment designer had been set a maximum dimension not to exceed, by the conceptual designer (for higher level reasons), then an inter level communication would be required if the embodiment level designer was unable to meet the constraints, and a higher level designer-client communication may be required. With the GST project, the conceptual and embodiment designers were the same purposeful individual, this sort of communication was therefore internal to him i.e. the embodiment designer had the same set of beliefs as the conceptual designer (same individual), therefore the iterative process was without communication.

### ***(b) Designer - Co-Designer Interaction***

It is possible, that to an extent the alter-ego role did exist at the embodiment level. Although no individual was assigned to perform such a role, it appears likely that as a result of the third recursive level designer being responsible for determining all dimensions at the detail level, that he would have had a well developed set of beliefs about the embodiment level.

Unfortunately, it is likely that the belief system of the lower level designer would have been inadequate (due to his limited training) to take over at the higher level, if the embodiment designer was to depart prematurely for any reason. The lower level designer would however have provided an excellent source of information for any new designer at the higher level.

### ***(c) Designer - Functional Expert***

During the conceptual design phase, those involved as functional experts, are concerned with ensuring that the broad belief held within their sub-function, is integrated into the eventual design. For example, marketing will be concerned about what the market wants; when it wants it; and how much it is prepared to pay for it. Finance is concerned with what is it going to cost, how they are going to finance the venture, and whether it will effect the liquidity of the organisation. Production will be interested in timing the project to suit the schedule of other work, and what resources of men, materials and machinery will be required, while design will be more worried about the demands that the project will place on its resources. All of these views are important, and all need to be taken account of in some way. At the embodiment stage, however, functional experts will be providing information at a more specific level, within the framework of the decisions made at the higher level.

In the case of the container project, an example of this might be in relationship to the doors. At the higher level marketing may have considered that the curtain sided containers were desirable due to such features as the ease of loading. But at the more specific level

of embodiment design, marketing may be concerned about the effect on product appeal, if the doors appear *flimsy* and easily to damaged. They might, therefore, prefer a cheaper curtain door, to enable replacement every 12 months to keep the containers looking new.

The design office at the embodiment stage, would be considering what staff to assign to the project, to ensure its timely and successful completion. As the availability of designers (for emerging recursive levels) would obviously affect the time horizon of the overall design and determine the extent to which innovative, and thus time consuming, ideas could be incorporated. In the case of Railways this type of decision was unnecessary, since the embodiment designer was intended to be the conceptual designer from the beginning. The mechanical design office of Railways, is organised so that each engineer specialises in one or two types of wagons etc, thus allowing him to develop his skills and therefore the quality of his designs.

As with the conceptual level, there was no input from the production element concerned. In this way, any concerns about the development of the container, from a production view point, were not integrated into the designers belief system. As previously stated, this situation is attributable to a focus on sub-system optimisation rather than the total system, this is again exacerbated by a long held attitude toward the workshops.

#### ***(d) Designer - Belief Expander Interaction***

The designer of the GST obtained ideas for his project from a number of sources, as stated previously these included overseas magazines. He also approached trucking companies and investigated the way in which they handled containers, such as the way they lift them on and off trucks, and the type of *hard points* required to facilitate lifting. In terms of literature reviewing, at the embodiment level, the designer reviewed regulations for Road users, with regard to permissible loads and dimensions. He also studied Railways own guide-lines, for such things as allowable loads and dimensions for tracks, tunnels and bridges. In another

project, not related to the GST, it appears such an investigation was not carried out in sufficient detail, and as a result a new wagon was too large to fit through all the North Island tunnels - this was found out while the wagon was in operation!!

The role of Belief expander should not be underestimated, *Ford*, during the *Taurus* development, saved considerable sums of money by involving production staff in the design process. The suggestions made by these specialists resulted in a different approach to many aspects of the automobile, one example being a reduction in the number of door panels.

The production input is an obvious one in technical projects, but again this input was not sought. One shop floor worker, who was interviewed, felt that instead of the extremely complex and time consuming construction of the container ends (see figure 9.5) a more conventional pressed corrugated steel end could have been used (figure 9.6). This would have been significantly easier to make, quicker to construct, and therefore cheaper to produce, and from his years of experience he felt it would also make the container stronger. The final decision is always the designer's, however, if he has an incomplete set of beliefs, the decision he ultimately makes may not be the best in a given situation.



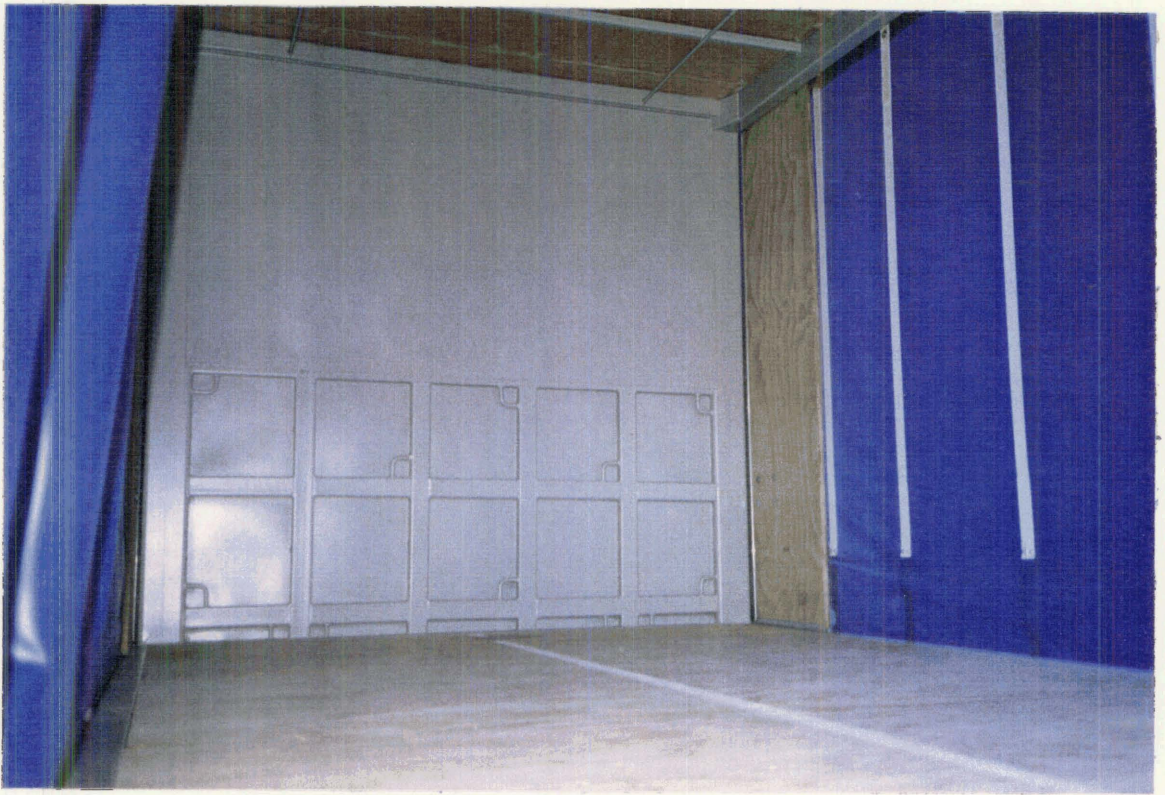


Figure 9.5 The Construction of the GST Container Ends



Figure 9.6 The Corrugated Construction of Conventional Container Ends



### **(e) Designer - Critic Interaction**

The critic role consists essentially of two different types of critical review. The first of these is when a critic determines that the designer's beliefs about a particular aspect of the design do not satisfy the overall objective under certain conditions. An example of this could be in the minimum diameter for a journal bearing in the design of a new engine. In this way the critic uses his specialist knowledge to determine under what conditions the designer's hypothesis fails to be valid.

The second type of critical appraisal, concerns finding areas where the designer's hypothesis would result in the artifact being difficult to produce, maintain or operate, for example.

Because the GST project was technically very simple, it is the second type of critics role that was most important. An example of the first type, however, would be a stress specialist indicating to the designer the load limits the container could carry. If these loads were below what the designer required, the designer would have to modify his design.

In the second role, a number of difficulties found with the GST container could have been overcome, if an effective critic's role had been performed. A very good production example was the width of the container floor. The chosen material for the floor was plywood, the standard dimensions of a sheet being 2400 mm x 1200 mm, yet the internal dimension of the floor was approximately 2350 mm (see figure 9.7).

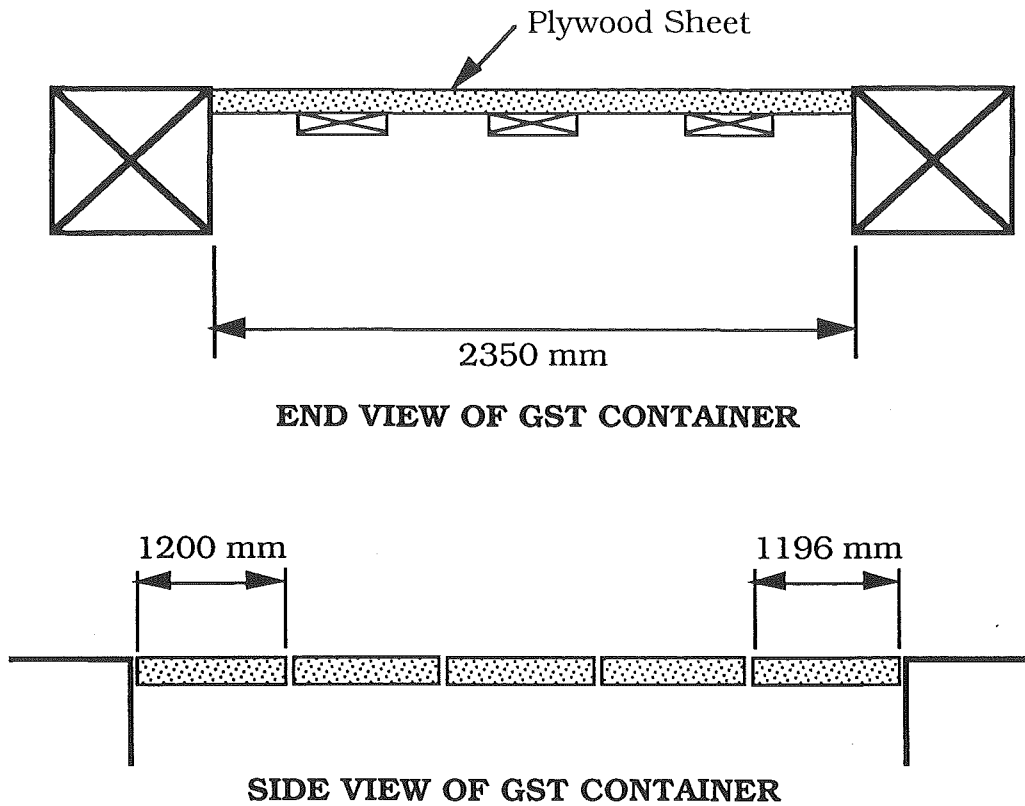


Figure 9.7 GST Container Floor Design

The result of this decision, was that that each of the sheets fitted to the 70 containers had to be cut to size. This was time consuming and therefore costly; it also infuriated the workmen constructing the containers.

Another difficulty that might have been overcome, had a user critic been involved, was the difficulty associated with loading and unloading the containers from railway wagons. In the case of most containers the design allows for them to be lifted using a *Top Lifter* (a top lifter is a fork lift type vehicle that clamps to the top of the container instead of using forks inserted into slots), in the case of the GST, the strength and method of construction did not allow for this type of handling, thus requiring the use of a less convenient conventional fork lift. Another difficulty that a user critic may have spotted was the door opening dimensions. The initial production models had a top structural beam, running along the top of each side, that was too big to allow the loading of some types of palletised goods, e.g. pallets of casked wine (see figure 9.8).

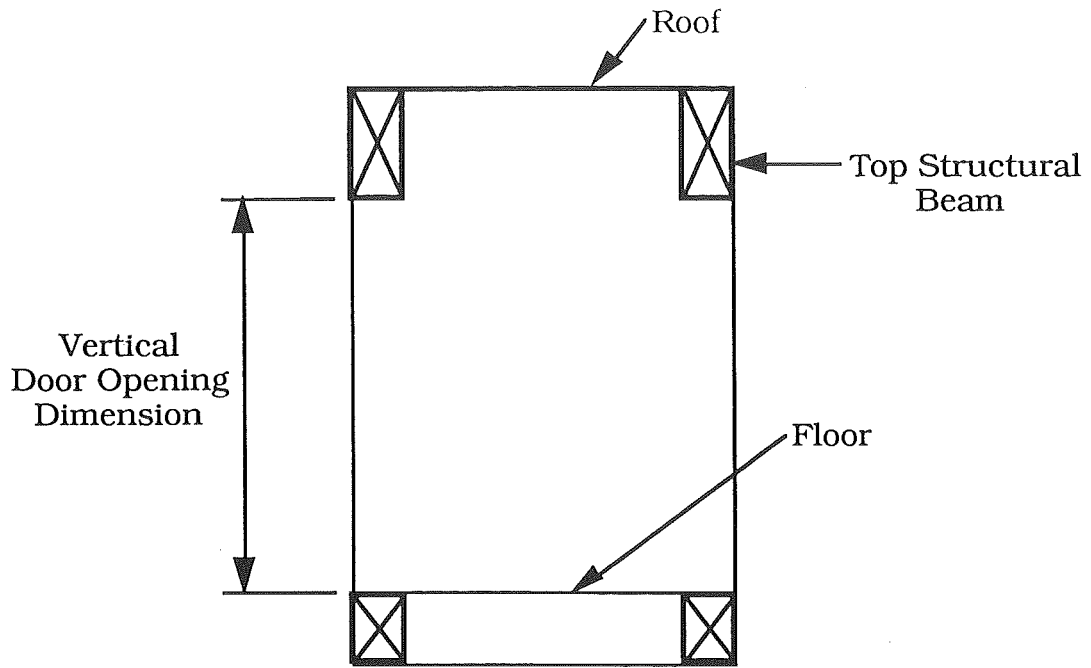


Figure 9.8 GST Container Structural Arrangement

This situation was eventually overcome by reducing the size of the beam, this however also indicates that the beam was over designed, a point that a stressing critic should have raised. Critical appraisal during the design stage is something that would in general be given limited attention, the difficulties highlighted above generally coming to light after the production of a prototype. Unfortunately, this would be after expending considerable time and effort, it is the aim of the PDM to help eliminate difficulties such as these before they are engineered into an artifact.

#### ***(f) Designer - Sub-Designer Interaction***

Unlike the step between purposeful designers at the conceptual and embodiment levels, the designers at the embodiment and detail levels were different individuals. The designer at the two highest levels is a university trained Mechanical Engineer, while the designer employed to carry out the detailed design work was a New Zealand Certificate of Engineering student.

Of importance here is whether the lower level designers belief system was developed enough to integrate fully with the higher level designer. It is difficult to assess this, however, as although there were a significant number of problems at the detailed level,

the lower level designer was in close contact with the higher level designer. In this way it is conceivable that the close contact with the embodiment level designer, ensured that the embodiment and detailed levels were adequately integrated.

When being interviewed, the designer commented that in general he preferred to keep to the conceptual and layout levels of design, and then leave a draftsman to take care of the detailed design work. However, he added that the ability to do this was dependent on the capabilities of the draftsman involved. This statement clearly indicates the designer's beliefs about the capabilities of the various design office draftsman.

If the designer was of the opinion that the draftsman's set of beliefs were inadequate for the task, then it would obviously result in him devoting more time to working at that lower level of recursion.

#### ***(g) Designer - Design Hypothesis Freezer***

As with the conceptual level design, the designer at the embodiment level, was responsible for determining when his design hypothesis should be frozen.

#### ***(h) Designer- Documentor Interaction***

The embodiment level of the GST project, did not vary from the conceptual level in terms of the documentor function. It was stated in section 8.2.1(h) that any categorisation of information or generation of documents associated with the design, were the responsibility of the designer. This was again the situation during the embodiment level design.

#### ***(i) Designer - Administrator Interaction***

At the conceptual level, the designer was responsible for all administrative tasks, this was again the case with the embodiment level designer. Thus the burdens spoken about in section 8.2.1(i) are still applicable.

Embodiment design in the GST project was not as well done as the conceptual level. A number of issues that should have been resolved, or taken account of, were not and as such decisions were made without a fully developed set of beliefs. This criticism is particular valid, if one looks back at the decision regarding the floor dimensions or the loading considerations. These factors are not so much organisationally based as ignorance based, if a critics role had been performed in a number of areas such difficulties need not have arisen.

### **9.2.3 Recursion 2 - Detailed Design**

Detail designing is the transformation of the broad technical solution into a form suitable for production. During this stage:

*the arrangement, form, dimensions and surface properties of all the individual components are finally laid down, the materials specified and all the drawings and other production documents produced [28].*

In the case of the Purposeful Design Model, final drawings and specifications are the task of the lowest level designer, in the case of the GST container this has been modelled as the third recursive level.

#### **(a) Designer - Client Interaction**

As in the case of recursion 1 (embodiment design), the designer at this level, will in general only communicate with the client to clarify points appropriate to the detail design. Such an example of this type of communication might concern the exact location of the locking mechanism on a door, or the placement of a handle for pulling doors shut.

If matter arise which affected the overall concept or layout of the design, then these would be matters for the higher level designers.

#### **(b) Designer - Co-Designer Interaction**

The majority of the design work, performed at this level of recursion, was performed by an New Zealand Certificate of

Engineering trainee, as such his performance was carefully monitored by the design office staff member he was working with, in this case the conceptual and embodiment designer. The result of this is that the higher level designer, who actually set the lower level objective (set of structural and functional properties), could have taken over from the recursion 2 designer should it have been necessary. In this way the co-designer's role was effectively being performed by the higher level designer.

***(c) Designer - Functional Expert***

The input of functional experts at this level of recursion, will as would be expected, be very specific, for example, marketing might want the container to be painted a specific colour to enhance its appeal, while manufacturing may inform the designer that a particular process, e.g. welding will be *bottle-necked* for the next few months, due to other projects, and that bolted joints may be a more appropriate solution considering the circumstances. In the case of the GST project there was no evidence of any interaction of this type at the third recursive level.

***(d) Designer - Belief Expander Interaction***

The role of the belief expander is to use his experience, such as the shop floor workers in the *Ford Taurus* project, to help the designer to see alternative ways of achieving the objective he is trying to satisfy.

In the case of the GST container project, there are a number of areas where an interaction of this type would have had significant benefits to the project.

One that would have saved a substantial amount of time, and thus money, concerned the method of fixing the floor and roof to their respective structures. The designer specified fasteners for securing the panels in place, while the production staff were in favour of gluing the floor and roof down. It was the belief of the shop floor staff, that the advances made in glues over the past decade, made it possible to substitute this for nuts and bolts. It

was further felt by the workers that the use of glue would have reduced the time to fit a containers floor, from four hours to approximately 30 minutes, and from about 2 hours to 30 minutes in the case of the roof. The resulting saving in time would be around five hours, or some 350 hour for the fleet of 70 containers, thus resulting in significant cost savings. When asked why he had elected to use the fasteners, the designer replied that it was his belief that glues were inadequate for the task. On reviewing the appropriate literature, however, the author found that the shop floor workers were indeed correct, and the use of modern adhesives was definitely a possibility. This situation clearly indicates that the designers belief system, with regard to glues, was inadequate for him to be able to make an informed decision regarding the use of alternative fixing methods.

Had the designer discussed such an issue, with those likely to build the containers, his belief system could have been expanded by their knowledge of the possible alternatives. The cost involved in the designer's decision was significant, and therefore had implications beyond the production department. The lower costs of production could have made a difference in making the project financially viable or how the project was financed, whatever the implications, the fact remains that the project suffered due to an incomplete set of beliefs on behalf of the designer.

In the case of a container or wagon it is necessary to locate *tie down* points for securing the load while the container is in transit, as well as handles for closing the doors. Generally the designer relies on his own belief system to locate such items, at points he considers appropriate. If the placement of these items ultimately turns out to be inappropriate, then it would suggest that the belief system used to make such decisions was inadequate.

During an interview with a user of the GST, such a situation was put to the author, the individual involved stated that he would:

*like to be involved not only in the conceptual design (which he wasn't anyway) but also help in making detailed decisions such as the precise location of handles and tie down points, as these make a big difference to*

*the ease with which wagons and containers are loaded and unloaded.*

Here is an example, where the individual making the comment has a fully developed belief about the situation discussed, while the person making the decision obviously does not. It is this lack of an integrated set of beliefs by the designer that the PDM aims to overcome.

### **(e) Designer - Critic Interaction**

Design for manufacture, design for quality, and design for a number of other important areas, are fields of research that have received a lot of attention in recent years. The purpose of the PDM is to help ensure that these different considerations are effectively incorporated, it is through the role of the critic that each aspect can be examined to look for improvement.

The instances discussed in the previous section, namely the floor and door dimensions, are also applicable to this one, as the lack of an adequate belief at the earlier stages could have been detected by the use of critics from each of the effected areas. Besides these two areas, a host of other difficulties could have been overcome prior to production, had a critical review been made during the design process.

One quite embarrassing mistake, made by the designer, was the inability to remove damaged doors. Until it was spotted by manufacturing staff, containers were built and doors fitted, without a facility to enable the easy removal of damaged curtains. In fact, another mistake made by the designer guaranteed that the doors would be damaged within a short period of time. This second problem was due to the curtains extending below the top of the *fork pockets* (the holes used by a fork lift for picking up the containers), see figures 9.9 and 9.10. As a result of this, curtains sustained damage within a very short period of time, therefore, requiring their replacement. However, because of the first design problem, it proved nearly impossible to remove the offending door, a modification was therefore required to expose the end of the curtain rail, see figure 9.11.





Figure 9.9 GST Curtain before Modification

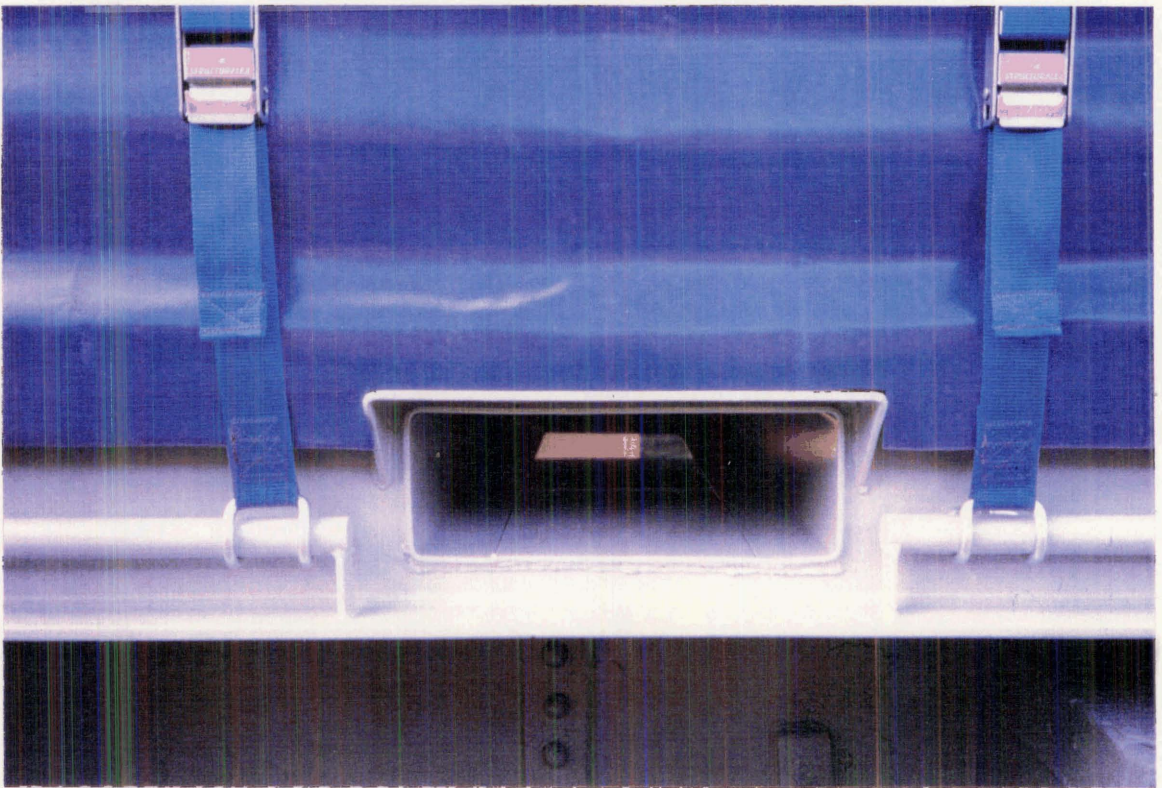


Figure 9.10 Curtain after Modification





Figure 9.11    Modification to Allow  
Curtain Replacement

Both of these problems should have been detected prior to manufacture had suitable critics been involved.

In the case of the curtains covering the fork pockets, anyone should have detected the problem, but it is almost certain that a fork lift driver would have. If maintenance personnel had been used in the critic's role, it is likely that the question would have been asked *How do you replace the curtains*, and a suitable solution found before commencement of production. Each of the individuals mentioned above has a set of specialist beliefs, it is through the use of these beliefs that weaknesses in the designer's

design hypothesis can be identified. This mechanism enables him to eliminate potential problems, before the commencement of production or the manufacture of a prototype.

***(f) Designer - Sub-Designer Interaction***

The level of detailed design is the lowest recursive level in any development project, as such there is no sub-designer for the detailed designer to communicate with.

***(g) Designer - Design Hypothesis Freezer***

As with the two previous recursive levels, the freezing of the design process was once again the decision of the designer.

***(h) Designer - Documentor Interaction***

Unlike the higher recursive levels, the detailed design of the GST resulted in a significant amount of information being generated for communication to the rest of the organisation.

Firstly the actual drawings were generated, taking the form of assembly drawings and piece part drawings. These were checked by senior design office personnel for drawing conventions and general drafting correctness.

Next a Railways *Bill of Material* was produced, this is unstructured and simply lists piece part drawing numbers, a description, a material specification and a few other details. It was noted that the workshops, after receiving this information, proceed to develop their own *Bill of Material*. In addition to the manufacturing information generated, verbal information was passed to users, such as the location of spare parts and how to go about getting them. In each case the detailed designer or the higher level designer performed the documentor's role, as would generally be expected in a small project.

### ***(i) Designer - Administrator Interaction***

As in the case of conceptual and embodiment design, all administrative tasks were the responsibility of the designer, specific administrative activities performed at this level are unknown.

In terms of the Purposeful Design Model, the detailed design of the GST container suffered from a number of violations, the result of this was a number of missed opportunities and production, operation and maintenance difficulties. While a number of these were eventually overcome, it was at significant cost to the project.

### **9.3 Summary of the GST Project**

The GST container was designed as a low cost, general usage goods container, for use on road and rail. As such the final product achieved its goals, this being evident by the demand for the product.

Its design and structure are **not** of a complex nature, and as such the difficulties associated with it are minor. However, the difficulties discussed in this analysis, do indicate that the project could have been even more successful. In all instances, the difficulties discussed have been the result of the designer not having an adequate belief system to make a number of the decisions made. In general, the lack of an appropriate belief system is the result of the designer not integrating a sufficient number of views into his own, resulting in a myopic view of the problem.

The views of other parties were in general excluded for two reasons, firstly an ignorance to the need for input, beyond that of just the designer, and secondly, strongly enforced organisational boundaries, with profit and long standing attitudes acting as the dividing mechanism.

The relationship between the commercial freight arm of Railways and the workshops is complex, this has been made more so by

confusing the organisational recursion within which the production facilities operate. However, the difficulties associated with this confusion appear to be being overcome slowly: for example in the week before Christmas 1990, New Zealand Rail Limited closed down two of its remaining workshops, including the one dealt with in this project, with no promises that the final three will survive in the long run.

Considering the down scaling of the workshops over the past decade, it is likely that within the next few years, Railways manufacturing needs will have to be satisfied by the private sector engineering industry. This will reduce the complexity of the necessary interaction, for the operational elements of Railfreight Systems, and in the short term may well prove to be financially, and organisationally beneficial, should the New Zealand economy remain depressed.

Note: The PDM provides a description of the roles important in the development of design hypotheses, in an ideal situation all the roles should be performed, however, in a real world situation it may be impossible or impractical to perform all the roles effectively. The decision to design the GST container so that it could not be lifted by a *Top Lifter* is an example of this, here the designer's time constraint required him to make decisions without the benefit of full consultation with all those likely to be affected by the design decisions to be made.

Additionally, even if consultation does occur it may be difficult for individuals to visualise the intended artifact before it is built, thus making it difficult, if not impossible, for some individuals to perform the roles described here before they have the benefit of viewing a prototype.

## CHAPTER 10

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### CONCLUSION

This thesis has looked at the integration problem that exists between design and production within manufacturing organisations, and develops a solution based on the integration of beliefs during the development of design hypotheses.

Integration is a two pronged problem, firstly there are the problems associated with the effective operation of the firm as a system. To analyse the relationship between functional groups, and to assess the structural reasons for the causes of dis-integration, Stafford Beer's *Viable System Model* is used.

The inability to develop an integrated system of beliefs, and therefore valid design hypotheses, has been discussed as the cause of integration problems at the level of the individual. It was stated that the fundamental cause was the decline of the *integrated individual*, someone whose life experiences enabled them to empathise with members of different functional groups. These life experiences, developed through years of on the job training within the many areas and levels of an organisation, providing the individual with a broad system of beliefs on which to integrate the requirements and concerns of functionally diverse groups, during the process of hypothesis development.

The *Purposeful Design Model*, through a system of designed roles, enables an individual to develop an integrated system of beliefs, for the development of valid hypotheses, and thus achieve the same level of success as his fully integrated forebears. Through parallel application of the model, in the various developmental functions of an organisation, it is maintained that the *Purposeful Design Model* represents a system for developing organisational wide, integrating and coordinating plans for the product development process.

To enable the reader to appreciate the diverse application of the *Purposeful Design Model*, a number of case studies have been considered, each of these discussing a systems failure based on a lack of integration. The *Purposeful Design Model* and Beer's *Viable System Model*, are used to analyse the reasons for those failures, and to put forward possible solutions for similar situations. Through these case studies, the power of the *Purposeful Design Model* as a diagnostic tool, and a potential hypothesis management system, is demonstrated.

The roles that comprise the *Purposeful Design Model* are those that are considered necessary and sufficient for the development of valid design hypotheses. It is considered that these roles are also fundamental to the tasks that are performed in the day today operation of an enterprise, and that in fact they may be a sub-set of a wider system of work roles necessary for the operation of an organisation; where all activities in the wider organisation are comprised of collective sets of work roles, the mix of the roles being dependent on the task to be achieved.

Further research is required to establish the existence of further work roles and the way in which they must interact to ensure wider organisational integration. From this basis investigation into the training of individuals, both in academic institutions and within organisations, can be conducted so as to determine the most efficient use of the training resource.

## REFERENCES

- [1] Whitney, P.E., Nevins, J.L. *Concurrent Design of Products and Processes - A Strategy for the Next Generation in Manufacturing*. McGraw-Hill (1989).
- [2] Harrington, J. *Understanding the Manufacturing Process*. Marcel Dekker (1984).
- [3] Blackburn, D., Holister, G. *Hutchinson Encyclopedia of Modern Technology*. Equinox (Oxford) Ltd. (1987).
- [4] Hounshell, D.A. *From the American System to Mass Production, 1800-1932*. The Johns Hopkins University Press (1984).
- [5] Smith, G.G. *Frederick Henry Royce - An Outline of his Engineering Achievement*. Longmans, Green & Co Ltd. (1945).
- [6] Medlock, R.S. *Practical Training in Industry of the Graduate in Mechanical Engineering: Part III*. I MECH E, Vol 168 (1954).
- [7] Evan, K.R. *Practical Training in Industry of the Graduate in Mechanical Engineering: Part I*. I MECH E, Vol 168 (1954).
- [8] Pope, J.A. *Practical Training in Industry of the Graduate in Mechanical Engineering: Part IV*. I MECH E, Vol 168 (1954).
- [9] Beer, S. *Diagnosing the System for Organisations*. John Wiley and Son Ltd. (1985).
- [10] Britton, G.A., Whybrew, K. *Computer-Aided Integrated Manufacture: A Critique*. Submitted for Publication (Dec 1990)
- [11] Burbidge, J.L. *The Introduction of Group Technology*. Heinemann (1975).
- [12] Beeby, W.D., Thompson, A.R. *A Broader View of Group Technology*. Computers and Industrial Engineering Vol 3 (1979).
- [13] Opitz, H. *A Classification System to Describe Workpieces*. Pergamon Press (1970).



- [14] Hyde, W.F. *Improving Productivity by Classification, Coding and Data Base Standardisation - The Key to Maximising CAD/CAM and Group Technology*. Marcel Dekker Inc. (1981).
- [15] Knox, C.S. *CAD/CAM Systems - Planning and Implementation*. Marcel Dekker (1983).
- [16] Burgidge, J.L., Falster, P., Riis, J.O., Svendsen, O.M. *Integration in Manufacturing*. Computers in Industry, **9** 1987.
- [17] Burbidge, J.L., Falster, P., Riis, J.O. *Integration Audit - A systematic method for studying a manufacturing enterprise to determine possibilities for integration*. Computer Integrated Manufacturing Systems, Vol 2, **3**, (1989).
- [18] Whitney, D.E. *Designing for Producibility - Manufacturing and Design: A Symbiosis*. IEEE Spectrum, 1987, **5**, 47.
- [19] Heidenreich, P. *Designing for Manufacturability*. Quality Progress, May 1988.
- [20] Institution of Production Engineers. *A Guide to Design for Production*. Institution of Production Engineers (London) 1984.
- [21] Andreasen, M.M., Kähler, S., Lund, T. *Design for Assembly*. IFS (Publications Ltd/Springer-Verlag) (1983).
- [22] Boothroyd, G. *Design for Assembly - The Key to Design for Manufacture*. The International Journal of Advanced Manufacturing Technology, Vol 2, **3**, (1987)
- [23] Andreasen, M.M., Olesen, J. *The Concept of Disposition*. Journal of Engineering Design, Vol 1, **1**, (1990).
- [24] Matousek, R. *Engineering Design - A Systematic Approach*. Blackie & Son Ltd. (1963).
- [25] Asimow, M. *Introduction to Design*. Pretice-Hall Inc. (1962).
- [26] Evans, B. *Simultaneous Engineering*. Mechanical Engineering, Feb (1988).
- [27] Andreasen, M.M., Hein, L. *Integrated Product Development*. IFS (Publications) Ltd/Springer-Verlag (1987).
- [28] Pahl, G., Beitz, W. *Engineering Design*. (Wallace, K.M. ed). The Design Council (1984).

- [29] Hubka, V. *Principles of Engineering Design*. (Eder, W.E. ed) Butterworth & Co (1982).
- [30] Hubka, V., Eder W.E. *Theory of Technical Systems*. Springer-Verlay (1988).
- [31] VDI 2221: *Systematic Approach to the Design of Technical Systems and Products*. (VDI) Verein Deutscher Ingenieure (1987).
- [32] Hales, C. *Analysis of the Engineering Design Process in an Industrial Context*. Ph.D. Thesis, Department of Engineering, Cambridge University (1986).
- [33] Checkland, P. *Systems Thinking, Systems Practice*. John Wiley & Son Ltd. (1981).
- [34] Vernilli, R.J., Meunier, K.L., Dixon, J.R., Simmons, M.K. *Iterative Respecification Management: A Model for Problem-Solving Networks in Mechanical Design*. Computers in Engineering, Vol 1 (1987).
- [35] McCall, R.J. *Issue-Serve Systems: A Descriptive Theory of Design*. Design Methods and Theories, Vol 20, 3, (1986).
- [36] Ward, A.C. *A Recursive Model for Managing the Design Process*. Submitted to 1990 ASME Conference on Design Theory and Methodology.
- [37] Stomph-Blessing, L.T.M. *Analysing an Engineering Design Process in Industry*. Proceedings of the Institute of Mechanical Engineers International Conference on Engineering Design, ICED 89 (1989).
- [38] Krause, F. *Knowledge Integrated Product Modelling for Design and Manufacture in Organisation of Engineering Knowledge for Product Modelling: A collection of contributions based on lectures presented at the 2nd Toyota Conference*. (Sata, T. ed) (1988).
- [39] Pugh, S. *Design Activity Model: Worldwide Emergence and Convergence*. Design Studies, Vol 7 (1986).
- [40] BSI 7000. *Guide to Managing Product Design*. British Standards Institute (1989).
- [41] The Concise Oxford Dictionary, 7th Edition Oxford University Press (1983).
- [42] Merchant, M.E. *The Future of Batch Manufacture*. Phil. Trans. R. Soc. London, A275 (1973).

- [43] National Research Council. *Computer Integraton of Engineering Design and Production - A National Opportunity*. Committee on the CAD/CAM Interface, Manufacturing Studies Board, Commission on Engineering and Technical Systems. Report PB 85-128429 (1984).
- [44] Beer, S. *Brain of the Firm*. 1st ed. John Wiley & Son Ltd. (1972).
- [45] Beer, S. *Platform for Change*. John Wiley & Son Ltd. (1975).
- [46] Beer, S. *The Heart of Enterprise*. John Wiley & Son Ltd. (1979).
- [47] Espejo, R. *Cybernetic Method to Study Organisations*. Paper to have been presented to the Society of General Systems Research (1987).
- [48] Espejo, R. *Information and Management: The Cybernetics of a Small Company*. University of Aston Management Centre, England. Working Paper Number 125 (1979).
- [49] Espejo, R. *Cybernetic Praxis in Government: The Management of Industry in Chile 1970 to 1973*. University of Aston Management Centre, England. Working Paper Number 174 (1980).
- [50] Schwaninger, M. *Embodiments of Organisational Fitness: The Viable System Model (VSM) as a Guide*. Systems Practice, Vol 3, 3, (1990).
- [51] Schwaninger, M. *A Practical Approach to Strategy Development*. Long Range Planning, Vol 20, 5, (1987).
- [52] Britton, G.A., McCallion, H. *A Case Study Demonstrating Use of Beer's Cybernetic Model of Viable Systems*. Cybernetics and Systems: An International Journal, Vol 16 (1985).
- [53] Ackoff, R.L., Emery, F.E. *On Purposeful Systems*. Tavistock Publications (1972).
- [54] Ackoff, R.L. *Scientific Method: Optimising Applied Research Decisions*. John Wiley & Sons (1962).
- [55] Bertalanffy, L. von. *General System Theory*. Braziller (1968) - Includes reprints of *The Organism Considered as a Physical System* (1940).
- [56] Buchanan, D.A., Huczynski, A.A. *Organisational Behaviour: An Introductory Text*. Prentice-Hall Internationa (1985).

- [57] Kast, F.E., Rosenzweig, J.E. *Contingency Views of Organisation and Management*. McGraw-Hill (1979).
- [58] Lawrence, P.R., Lorsch, J.W. *Organisation and Environment*. R.D. Irwin Inc. (1969).
- [59] Cheng, H., Skevington, C. *Integration of Data and Knowledge in Manufacturing Enterprises: A Conceptual Framework*. J. Manu. Sys. 1987, 4, 277.
- [60] Ackoff, R.L. *Redesigning the Future: A Systems Approach to Societal Problems*. John Wiley & Sons (1974).
- [61] Amey, L.R. *Corporate Planning: A Systems View*. Praeger Press (1986).
- [62] Wortman, M.S., Luthans, F. *Emerging Concepts in Management: Process, Behavioural, Quantitative, and Systems*. MacMillan (1975).
- [63] Hainmann, T., Scott, W.G. *Management in the Modern Organisation*. Houghton Mifflin (1970).
- [64] Fox, W.M. *The Management Process*. R.D. Irwin, Inc. (1973).
- [65] Britton, G.A. *Modelling Technical Manpower*. Ph.D. Thesis, University of Canterbury, New Zealand (1978).
- [66] Argenti, J. *Systematic Corporate Planning*. Thomas Nelson & Son Ltd. (1974).
- [67] Institution of Production Engineers. *A Guide to the Management of Design*. Institution of Production Engineers (1989).
- [68] Espejo, R., Harnden, R. *The Viable System Model - Interpretations and Applications of Stafford Beer's VSM*. John Wiley & Sons (1989).
- [69] Ashby, W.R. *An Introduction to Cybernetics*. Chapman and Hall Ltd. (1956).
- [70] Emery, F.E., Trist, E.L. *Towards a Social Ecology*. Plenum Press (1973).
- [71] Brooks, F.P. *The Mythical Man-Month: Essays on Software Engineering*. Addison-Wesley (1975).
- [72] McCallion, H.; Britton, G.A. *Effective Management of 'Intellectual' Teams with Specific Reference to Design*. Submitted for Publication in Journal of Engineering Design (Jan 1991).

- [73] Cortes-Comerer, N. *Motto for Specialists: Give some, get some.* IEEE Spectrum 1987, **5**, 41.
- [74] Petroski, H. *To Engineer is Human.* St. Martin's Press (1985).
- [75] Pratt, M.J. *Form Features and their Applications in Solid Modelling.* Advanced topics in Solid Modelling. SIGGRAPH CONF. (1987).
- [76] Pratt, M.J. *Synthesis of an Optimal Approach to Form Feature Modelling.* Proc. ASME Companies in Engineering Conf. (1988).
- [77] Lim, B.E.; Lim, B.S.; Lim, Y.G.; Ong, B.L. *Extraction of Technological Information from Feature Oriented Modelling System for Generative Computer Aided Process Planning.* Submitted to the International Conference on Productivity, 1989.
- [78] Beer, S. *Decision and Control.* John Wiley and Sons Ltd. (1966).
- [79] Peters, T. *Thriving on Chaos.* Harper and Row, Publishers, Inc. (1988).
- [80] MacCrindle, R.A.; Godfrey, P. *Rolls Royce Ltd: Investigation under Section 165(a)(i) of the Companies Act 1948,* Her Majesty's Stationery Office (1973).
- [81] Parker, R.J.; Pope, J.A.; Davidson, J.F.; Simpson, W.J. *The Fixborough Disaster: Report of the Court of Inquiry.* Department of Employment, Her Majesty's Stationery Office, London (1975).
- [82] Denzin, N.K. *Sociological Methods: A Sourcebook.* McGraw-Hill (1978).
- [83] Madge, J. *The Tools of Social Science,* Longmans (1953).
- [84] Gorden, R. *Interviewing: Strategy, Techniques and Tactics.* Dorsey Press (1980).
- [85] Zeisel, J. *Inquiry by Design.* Cambridge University Press (1984).
- [86] Webb, S. *Methods of Social Study.* Cambridge University Press (1975).
- [87] Garrett, A. *Interviewing: Its Principles and Methods.* Family Service Association of America.

- [88] Leitch, D.; Stott, B. *New Zealand Railways: The First 125 Years*. Heinemann Reed (1988).
- [89] New Zealand Railways Corporation. *Time for Change*. New Zealand Railways (1979).
- [90] New Zealand Railways Corporation. *The Social Role*. New Zealand Railways (1980).
- [91] Booz, Allen, Hamilton Consultants. *Comprehensive Review of Operations and Strategic Options Evaluation*, New Zealand Railways Corporation. New Zealand Railways Corporation (1983).
- [92] New Zealand Railways. *New Zealand Railways: The Path To Profit or The Engineers Contribution*. Handout to Final Year Engineering Students. (1990).
- [93] New Zealand Railways. *Press Release*. Christchurch Press (Nov 1990).

## APPENDIX A

### STAFFORD BEERS VIABLE SYSTEM MODEL: NON-TECHNICAL VERSION.

by G.A BRITTON & H. McCALLION. 1989.

#### INTRODUCTION

The viable system model (VSM) was developed by Stafford Beer over a period of about 30 years (Beer, 1984). During that time Stafford sought the basis of viability of complex, dynamic systems. He found the answer in cybernetics and developed a cybernetic model of viability (Beer: 1959, 1962, 1966, 1979, 1981, 1985).

What is cybernetics? Initially it was defined as the 'science of information and control'. That is, it is a science like physics and chemistry. However, its subject matter is any complex system regardless of what it is made of. The early work focussed on the information and control aspects of systems: on how they process information and how they achieve control. A distinguishing feature of cybernetics is that the systems which are studied are exceptionally complex.

More recently the science has been defined as 'the science of organisation and control'. The emphasis has shifted away from the information aspects to the organisational aspects. It is within the new context that the VSM must be viewed. You can also note that Stafford's work is different from main stream cybernetics. Consequently most of the criticism of cybernetics does not apply to Stafford's work.

The viable system model is a cybernetic model defining the criteria for effective control and organisation of complex systems. It describes the essential features of *dynamic behaviour* necessary for a complex system to maintain its *identity* despite *unforeseen* environmental disturbances.

The model is recursive. Recursion means invariant pattern. The model assumes that the pattern of organisation and control is the same at each level of control (management) and that the pattern of interactions between any two levels is the same for all pairs of levels. Recursion is a tremendously powerful concept. It means the same model can be applied to a worker, a work group, a corporation or large organisation, an industry, and a nation. The only thing that changes is the specific content of the model at each level of recursion.

The model includes the following essential characteristics of a viable system at one level of recursion:

1. Complexity: the parts of the viable system are innately complex, the internal connectivity is complex, and environmental connectivity is complex. Consequently the VSM only applies to systems that are goal-seeking or purposeful.
2. Maintenance of internal stability despite *unforeseen* environmental disturbances.
3. Learning from repeated experience the optimal response to a disturbance.
4. Robustness against internal breakdown and error.
5. Continuous adaptation to a changing environment.
6. Maintenance of its identity while doing all of the above.

It is important to realise at the outset that the model divides dynamic behaviour into logical classes. A person or a department in an organisation may perform behaviours belonging to more than one logical class. As a result it is not possible to *directly* map an organisation chart onto the model.



The logical classes of behaviour are:

1. System 1: produces whatever the system does: it acts.
2. System 2: co-ordinates the behaviour of the elements in System 1 to prevent uncontrolled oscillation.
3. System 3: maintains internal stability.
4. System 3\*: monitors System 1 to ensure it is operating effectively: audit and improvement.
5. System 4: intelligence function and self-awareness (double-loop learning).
6. System 5: guarantor of identity (self-reflection): formulates an identity and ensures that the identity is maintained.

The six sub-systems constitute a viable system at one given level of recursion. System 1 is the unit that does something and which is being managed. The other sub-systems are part of the management system controlling System 1. The model will now be explained with specific reference to social groups, because they are the main concern of the course.

## **THE MODEL AT ONE LEVEL OF RECURSION**

### **SYSTEM 1**

System 1 consists of a number of operational elements. An operational element is shown in Figure 1. It consists of a management unit embedded in an operations embedded in an environment. In order to show the connections between these they are shown separately with arrows indicating two-way interaction. The operations is the doing unit. It is controlled by the management unit which is a selector.

The operations can maintain a constant state despite unforeseen environmental disturbances perturbing it. The constant state is achieved through dynamic adjustment of other variables: known as ultra-stability. *Ultra-stability* differs from *equilibrium* which is a static constant state of a system, and from *stability* which is a constant state maintained by a dynamic process despite foreseen disturbances. Ultra-stability is a vitally important concept. As engineers you are used to the notion of designing a system to be stable against environmental disturbances that you can foresee at the time of designing. But to achieve ultra-stability you must design the system to be stable against environmental disturbances you did not and could not foresee at the time of designing. This may seem like an impossible task, but it is not. It does require, however, a re-examination of how a system can achieve self-control. You can note that the ultra-stable states are the essential variables which determine the identity of the operational element.

The environment being inherently much larger than the operations can generate more variety (states) than the operations. If ultra-stability is to be achieved this variety must be matched by the operations. If it is not matched then the operations will be forced to unstable states by the environment. Variety must match variety (Ashby, 1973). The matching can be achieved by attenuating (blocking) the incoming variety and amplifying the outgoing variety.

Similarly the operations can generate more variety than the management unit. So the management unit must attenuate incoming variety from the operations and amplify its outgoing variety.

Over a period of time the amplifiers and attenuators will develop so that the varieties balance; hence managerial variety (V) tends to equal operational variety (V) which tends to equal environmental variety (V). The corollary is that only that environmental variety which can be matched is in fact dealt with. If the attenuators and amplifiers are poorly designed then the operations will not be able to withstand much environmental disturbance. It will be easily

disturbed from a stable state and in fact may never achieve stability: a situation known as crisis management in organisations.

Note that not all environmental variety must be blocked. Only that variety which threatens the essential variables - which will destroy the system - must be blocked. If the blocking is to be performed dynamically then other variety must enter the operations (and management unit) to enable corrective action to be taken. The aim in organisational design is to allow in as much variety as the organisation can withstand, without destroying it. Without the incoming variety there can be no organisational learning. Furthermore proper design of the amplifiers and attenuators will reduce the social and psychological costs of variety matching (management).

The essential variables (ultra-stable states) can be kept within their safe limits by using feedforward and feedback as shown in Figure 2. Considerable emphasis has been placed on feedback in the cybernetic literature and for good reason. If a disturbance moves an essential variable away from its stable state then feedback can correct it *without needing to recognise the disturbance itself*. Hence design against unforeseen disturbances is possible. What is required is a monitoring system to detect when an essential variable is moving away from its normal operating point and an acting system that can try out different actions to bring the variable back to its normal state. Control is exercised as the system is going out of control and it can always be kept in control, within the specified limits. Feedback control cannot maintain a fixed state: there will always be some fluctuation because 'error' is necessary to activate the feedback control system.

On the other hand, feedforward control does require recognition of the disturbance to activate the control system. However, in this case, it is possible to achieve a specified final state exactly.

System 1 consists of a set of operational elements interacting with each other (see Figure 3). In order to show the interactions graphically it is necessary to list the elements on the page. The

order of the elements is not significant: one element is not more important than another because it is higher on the page.

There are three major types of interactions that occur between the elements: direct, indirect and management. Direct interactions occur within the system between the operations themselves. The indirect interactions occur between the operations through the environment. The management interactions occur between the management units as they control the operations.

Figure 4 shows a management system managing System 1. But System 1 consists of ultra-stable systems connected to each other; hence in principle, System 1 will be ultra-stable. Then why do we need a higher order management system to manage System 1?

The reasons are that:

1. The ultra-stability may not be the 'right kind'. The 'wrong' variables may be being maintained constant, or the 'right' variables may be being maintained constant but at the 'wrong' mean value or within 'too large' a range of variation.
2. The time taken for System 1 to achieve stability may be too long. In fact it may fail to adapt in time and hence be destroyed.

The first two rules of the viable system basically state that we do not need to enter the operational elements in order to manage them. That is, the higher order management system should manage the interactions between the elements and that is all. The practical implication is that the each element operates *semi-autonomously*.

The higher order management system consists of sub-systems called System 2, System 3\* , System 3, System 4, and System 5.

### **SYSTEM 3** (see Figure 5)

We will now discuss System 3 (System 2 will be described later). System 3 is part of the management system controlling System 1. Its function is to maintain the stability of System 1. It deals with the immediate and short term future. Its aim is to maintain and improve the actual performance of System 1 compared to what System 1 is capable of doing. It is entirely inward looking and has no direct connection with the environment. In a company System 3 is responsible for ensuring that the existing resources are properly managed given the existing constraints.

In order to perform its function System 3 must take an overall view of System 1. That is it is concerned with the interactions between the operational elements and how to improve these to get better performance overall. Consequently there will be a sub-function of System 3 dealing with each major type of interaction: direct indirect and management.

Figure 6a shows two examples of System 3 acting for the benefit of System 1. It is assumed that the viable system is a manufacturing company. Selling the product is represented as part of the environment-operations loops and also by the indirect interactions.

The finance director is responsible for managing the management interactions as these are primarily financial. The production director is responsible for managing the direct interactions which will include material flows, energy usage, etc. Figure 6b shows the sales director managing the indirect interactions which primarily involve the selling of the product and servicing arrangements. Note that the purchasing function will also be concerned with managing indirect interactions - those relating to material and component purchases.

System 3 must communicate with System 1 in order to manage it. There are three communication channels between System 3 and System 1 (Figure 7). They are the command and resource

allocation channel, System 2 (co-ordination channel), and System 3\* (audit and improvement channel).

### **COMMAND AND RESOURCE ALLOCATION CHANNEL'**

(see Figure 7)

The operational elements must contribute to the viability of the system of which they are System 1 and therefore cannot do what they like. The mandatory constraints on their actions are communicated via the command channel. The channel also carries the reporting back information on how well the elements are performing with respect to the targets set by System 3. For a company the command channel transmits legal and company requirements, resources bargaining, and accountability.

It may seem that the constraints restrict the autonomy of the operational elements. The answer is Yes and No. It is true that there is some restriction on what the elements can do, but these are necessary to produce the co-operative behaviour between elements. The co-operative behaviour enables each element to do more than it could on its own. If there are no constraints then the result is anarchy: each element hindering rather than assisting the other elements.

### **SYSTEM 2 (see Figure 7)**

System 2 dampens oscillations due to the dynamic interaction between the operational elements. There are three main ways of interacting: pooled, sequential, and reciprocal (Thompson, 1967). Do not confuse these with the three types: direct, indirect, and management. The former refer to the ways in which the latter can actually be accomplished. For example, a direct interaction may be pooled, or sequential, or reciprocal.

Pooled interaction occurs when the elements have access to the same resources. It is the minimum that can exist for System 1 to exist as system. The appropriate System 2 for pooled interaction is timetabling, and/or allocation of priorities.

Sequential interaction occurs when the elements interact in a one-way sequence. The appropriate System 2 is standardisation and/or scheduling.

Reciprocal interaction occurs when the elements interact in a two- sequence. The appropriate System 2 is mutual adjustment in real time as the elements interact.

Examples of System 2 in a manufacturing company are engineering maintenance, quality control, production scheduling, and cash flow regulation.

### **SYSTEM 3\*** (see figure 7)

This gives System 3 direct access to the operations. Its functions are:

1. audit;
2. establishment of standard procedures to improve the overall performance of System 1;
3. investigate the need for and establish common services for System 1;
4. establish new modes of control under System 1 management supervision to improve overall performance of System 1.

Clearly some of the above functions are impossible for a biological system, such as a person. In biological cases, System 3\* performs an audit (balancing) role, ensuring that System 1 is not over stressed by Systems 2 and 3.

Examples of System 3\* are financial audit, quality audit, industrial engineering, and production engineering. A practical illustration of the three communication channels is given below for a computer services department in a manufacturing company. The actions of the department would be represented in the model as follows:

1. processing work on behalf of System 1: it is acting as part of System 1;
2. issuing commands to System 1: command channel;
3. determining work order priority and timetabling requests for service: System 2;
4. developing its services for the benefit of System 1: System

You can see now why the comment was made earlier that it is not possible to map a company's organisation chart directly onto the VSM. The computer department plays several different roles depending on what it is doing. The example is a very good reminder for you that the VSM describes dynamic behaviour.

The six vertical interactions - indirect, direct, management, command channel, System 2, and System 3\* - carry the variety to match the environmental disturbances affecting System 1. They should be designed to do so at minimum psychological, social and economic cost. Whatever variety is not absorbed by the three operational element interactions must be dealt with by System 3 and carried by the three channels of communication between System 3 and System 1.

The aim in organisational design is to produce a management system that uses the command axis minimally and yet still gives good control. Giving the operational elements maximal autonomy means that they can absorb more variety and hence reduce the management load. If the command channel is used minimally, then variety matching between System 1 and System 3 can only be achieved by having most of the variety flowing along the System 2 and System 3\* channels. In organisation theory this is called horizontal management (Peters, 1987).

Systems 1, 2, 3\*, and 3 are concerned with internal stability - with getting the best use out of the existing resources. This is a necessary prerequisite for any viable system (see also Drucker,



1980 chapter 1: managing the fundamentals). But a viable system must also adapt to changes in the environment. So we get System

**SYSTEM 4** (see Figure 8)

The functions of System 4 are intelligence and self-awareness. System 4 models the broader environment of System 1 (not the local environments of the operational elements) and creates a model of the viable system which can match it. That is, it generates and eliminates options for development.

System 4 deals with the broader environment, common to all the operational elements making up System 1, which directly or indirectly affects the local environments of the operational elements. This environment can be divided into two parts. The contextual environment includes only those aspects that are, or can be, known with a reasonable degree of certainty, i.e. for which there is a history. One could say it is the conservative environment. In a manufacturing company, Government economic policy would (should?) be part of the contextual environment.

The problematic environment includes the innovative aspects: those for which there is no history. New technological development would be part of the problematic environment. The reason it is called problematic is because it is just that. You are not sure what you are looking for, nor how to look for it. That is surely problematic!

The aim of System 4 is to develop the capability of System 1 given the current and expected environmental conditions. Development proposals may involve adding or deleting operational elements, and/or changing the management system - changing System 2, 3, 3, 4 and/or 5. System 4 must have a model of the viable system of which it is part if it is to perform effectively. The model provides a focus for the different System 4 activities and enables them to be properly integrated.

Typical System 4 activities in a company are product design and development, market research, corporate/business planning, management development, and organisation development.

Who regulates System 4? It regulates itself: that is why it has self-awareness. System 4 must ensure that it is operating effectively.

Actual change - adaptation - occurs as a result of interaction between Systems 3 and 4. Part of the interaction is due to competition for resources and part is due to getting agreement a particular proposal and how it is to be implemented.

The varieties of Systems 3 and 4 must be equal (balanced). Too much investment in System 4 and there will be cash flow problems leading to bankruptcy or receivership. Too much investment in System 3 and there will be no development and therefore loss of markets leading to bankruptcy or receivership. The 3-4 interaction is critical to viability and is difficult to get right in practice. Drucker (1980) makes some practical suggestions on how this can be achieved in a company.

Implementation of development proposals should be the responsibility of System 4. Once the development is complete it can be handed over to System 3 for normal operational control. This ensures clear accountability for proposals and that System 4 performs effectively.

The model appears to show that System 4 has authority over System 3. System 4 should have authority to implement proposals and therefore in this sense it does have authority over System 3. Also people at System 4 may be experts in their fields. The System 3 managers won't be and hence the 4 people can have 'expert authority' over 3 people. From the organisational viewpoint this issue is only important when the 3 and 4 people are different.

## **SYSTEM 5** (see Figure 9)

Systems 3 and 4 are both ultra-stable and hence, in principle, their interaction will be ultra-stable. But remember our previous argument regarding System 1. In practice instability may occur so we need another system to take care of any instability. Hence we get System 5.

The function of System 5 is to guarantee the stability of the 3-4 interaction. It determines the identity of the viable system: what it will be like.

Many different people and groups of people make up System 5 and contribute to the particular identity of a social group, e.g a company. In organisation theory this is called the stakeholder view (Ackoff, 1981). The stakeholders are all those people directly affected by the social group (company). In practice one person is, or a group of people (Board of Directors) are, accountable for ensuring that the stakeholders contribute to the identity of the group.

## **AROUSAL FUNCTION** (see Figure 9)

The discussion so far has focussed on stability and to ensuring that everything runs smoothly. But what happens if something goes wrong? How is top management (Systems 3, 4 and 5) to be alerted? The answer is an arousal function.

The arousal function has to detect when an essential variable is or is likely to go outside its normal limits and then alert Systems 3, 4 and 5. Detection of abnormality is performed by monitoring the data flowing in System 2. Then an alerting signal is sent to the appropriate managers at 3, 4, and 5.

But that is not all. The managers have a preset time period within which they must regain control. If they fail to bring the system under control within the time period the arousal function will alert the management at the next higher level of recursion. The next

higher level management also has a preset time period for regaining control. If the managers at the next higher level fail to regain control within their time period then an alerting signal is sent to the next higher level. And so on.

It is possible that loss of control within a work group, due to strike say, could result in an alerting signal to the Government of a country. If that happens then all the management levels between the group and the Government have failed to gain control (manage properly). A very serious state of affairs indeed! But it did happen in Chile under Allende due to Western (primarily USA) subversion.

You can see that the arousal function does two things. It alerts management when something is or is likely to go wrong by monitoring System 2 data flows. And it alerts management when a lower level of management fails to regain control in time.

The result of the alerting signal is to change the mode of management. The management system is 'toned up' and must deal with the 'crisis' quickly. You could say it goes into a 'crisis' mode - but don't confuse this with crisis management which is a perpetual state of crisis. In organisation theory, a similar concept is management by exception.

**SUMMARY**

At any level of recursion the viable system consists of six sub-systems. The sub-systems and their viability and planning functions are listed below.

SUB-SYSTEM NAME	VIABILITY FUNCTION	PLANNING FUNCTION
System 1	Action	Action
System 2	Coordination	Tactical Planning

System 3*	Audit, Improvement	Operational Planning
System 3	Operational Control	Operational Planning
System 4	Intelligence, Self-awareness	Strategic Planning
System 5	Guarantor of Total Stability	Normative Planning

Now for an interesting comment. It may be thought that we need different people at each sub-system level. But we don't! One of the major findings of early cybernetics was the idea of distributed control (Systems 2, 3\*, and 3). In recent times this idea has been extended to distributed development (System 4) and distributed values - identity ( System 5). These exciting ideas have lead to new ways of designing and managing organisations. To take one example. Traditionally the rule was one worker - one boss, with each boss controlling no more than about 10 workers. But if the workers operate as self-managed teams, then one boss (the supervisor) can manage 50-100 workers - they do this in Japan. Not only is the job more satisfying for workers under these conditions, but the managerial overhead is significantly reduced.

**LEVELS OF RECURSION**

**INTRODUCTION**

The cartoon in Figure 10 gives you a basic idea of recursion. Figure 11 applies the notion to levels of systems and environments. There are three levels of systems shown with their respective environments. Note how the lower level systems and environments are contained within the higher ones. The reason for levels of environments corresponding to levels of systems is that at each system level there are emergent system properties. Consequently there will be different environmental factors affecting the system.

Figure 12 shows levels of recursion for a large corporation. At each level there are three operational elements shown. The number three is not significant: it has been used for convenience. Figure 13 shows levels of recursion for trade training in New Zealand.

Now that you have some idea of levels of recursion let us see how two recursive levels are linked. Figure 14 shows the linking between two levels. When we want to explain the management at Recursion  $x$  we do so using the model shown in black: that is, the viable model. However the whole viable system at Recursion  $x$  is itself an operational element at the next higher level of recursion: Recursion  $w$  - shown in red. So depending on which level we are working at, we describe the system we are studying either in black or in red. That is, either as a viable system or as an operational element.

The linking between the two is as shown. The lower level detail becomes aggregated at the higher level. The full interconnections between the two levels are shown in Figure 15.

## **DIMENSIONS OF RECURSION**

In order to model the levels of recursion you have to select a particular viewpoint. There are always alternative viewpoints and hence different ways of modelling the levels of recursion. Each way is called a dimension of recursion. As an example, consider a company involved in project management and engineering consulting. Do we model on the basis of the projects being undertaken; or do we use the functional (specialist) departments e.g design, studies, etc; or do we use a breakdown according to the market (the clients)? All are feasible approaches. We will see later how one ought to make this decision. The important point to note at this stage is that there are alternative ways of modelling the recursive levels.

As an interesting aside, you can note that in the case quoted above, I actually modelled all three dimensions. I used each dimension to elucidate different aspects of the business. Two dimensions were

used to improve the management systems. One was used for project management, the other for corporate management. The third dimension was used to assist the development of a business strategy with respect to the clients. The corporate dimension being the *main one* had to incorporate the results from the other dimensions.

## REFERENCES

- |                |       |   |
|----------------|-------|---|
| Ackoff, R.L.   | 1981. | Creating the Corporate Future.  |
| Ashby, R.      | 1973. | An Introduction to Cybernetics. (1st published 1956.  |
| Beer, S.       | 1959. | Cybernetics and Management.   |
| ibid           | 1962. | Towards the Cybernetic Factory. In Principles of Self-Organisation, ed. von Foerster & Zopf Transactions of Illinois Symposium 1960.                  |
| ibid           | 1966. | Decision and Control.   |
| ibid           | 1972. | Brain of the Firm (1st edition).  |
| ibid           | 1979. | Heart of Enterprise.  |
| ibid           | 1981. | Brain of the Firm (2nd edition).  |
| ibid           | 1984. | The Viable System Model: Its Provenance, Development, Methodology and Pathology. Journal of the Operational Research Society, Vol 35, No. 1, pp 7-25. |
| ibid           | 1985. | Diagnosing the System for Organisations   |
| Drucker, P.    | 1980. | Managing in Turbulent Times.  |
| Thompson, J.D. | 1967. | Organizations in Action..   |

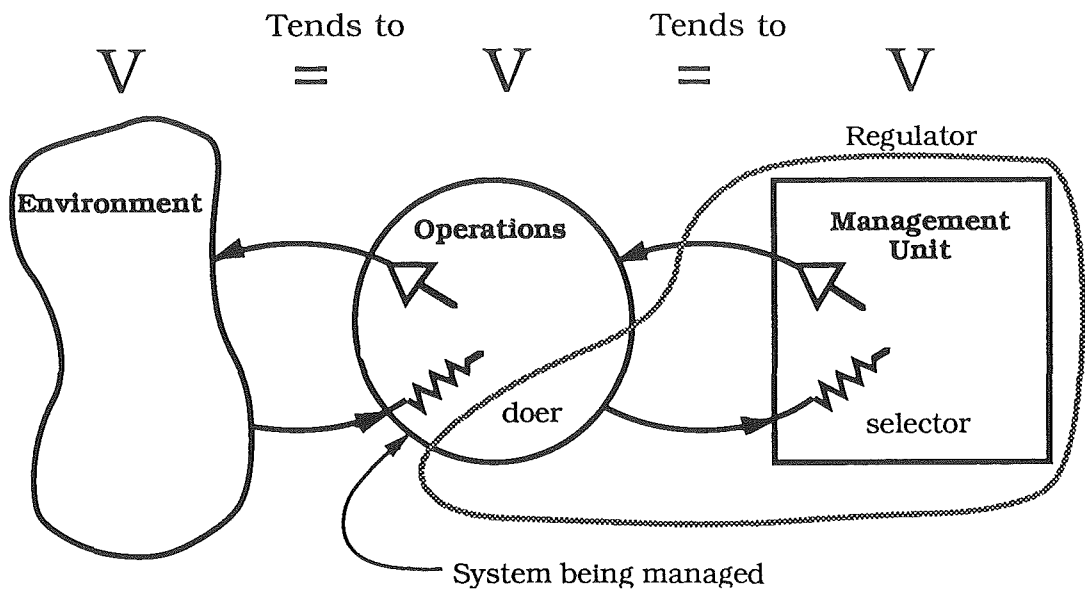


Figure 1 An Operational Element

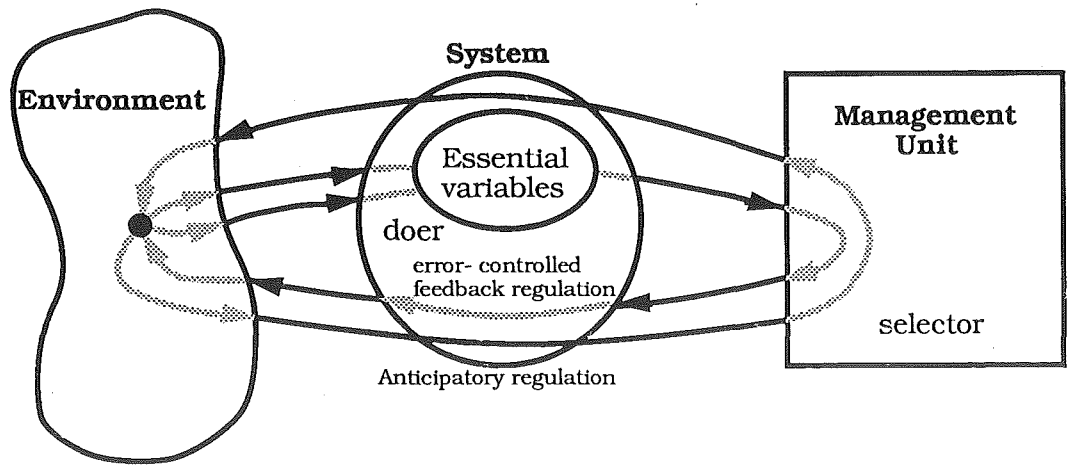


Figure 2 Two Ways of Achieving Regulation



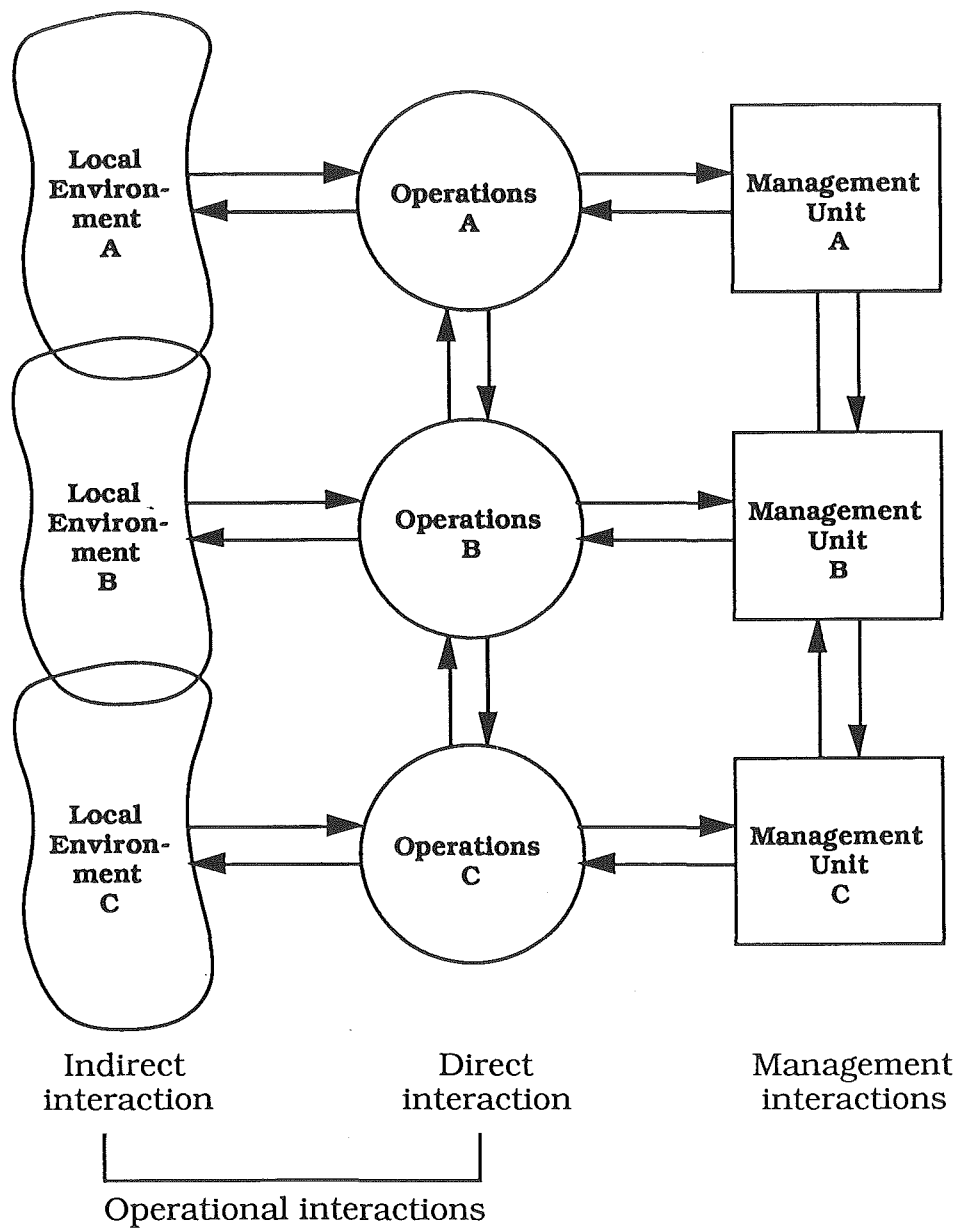


Figure 3 System 1: An Interacting Set of Operational Element

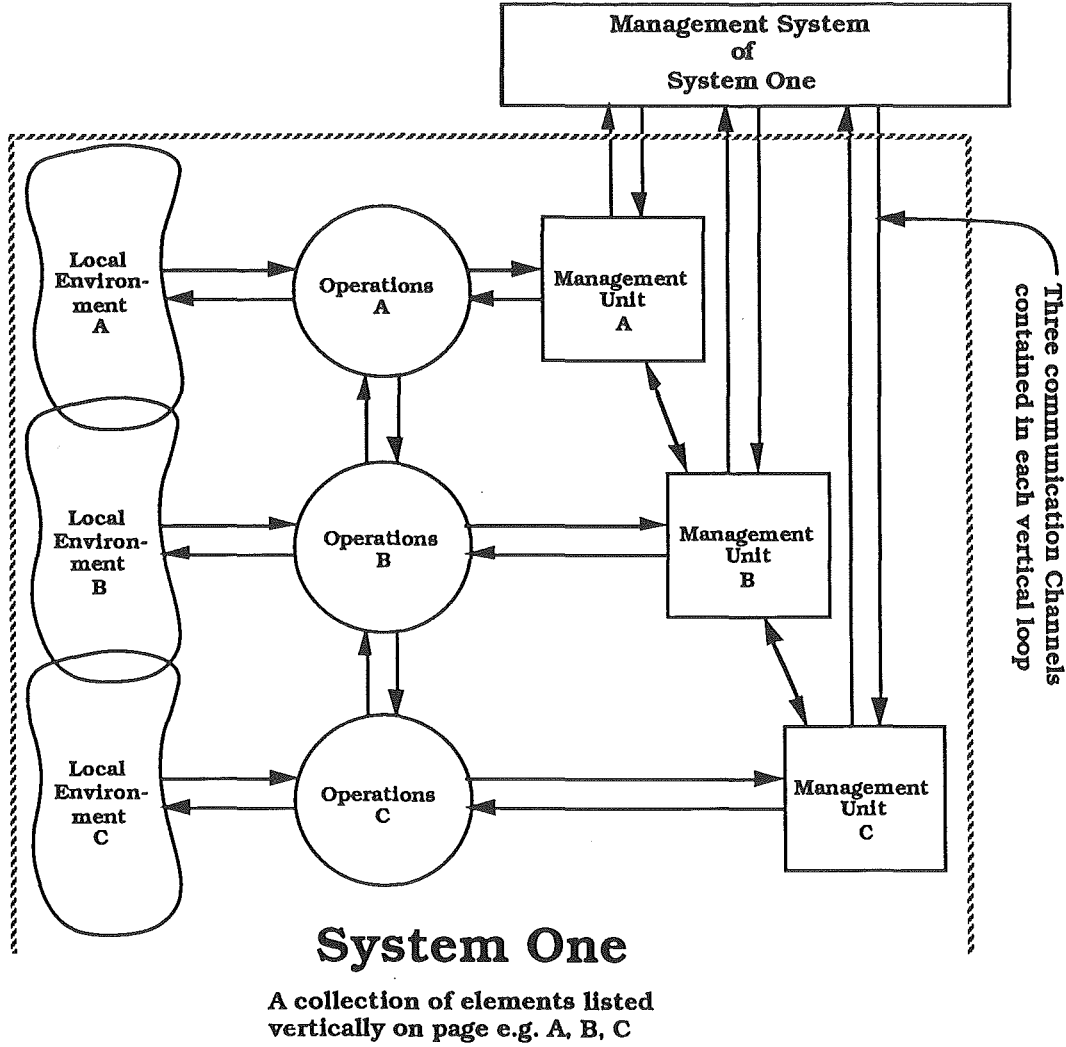


Figure 4 Two Level Hierarchy of Model

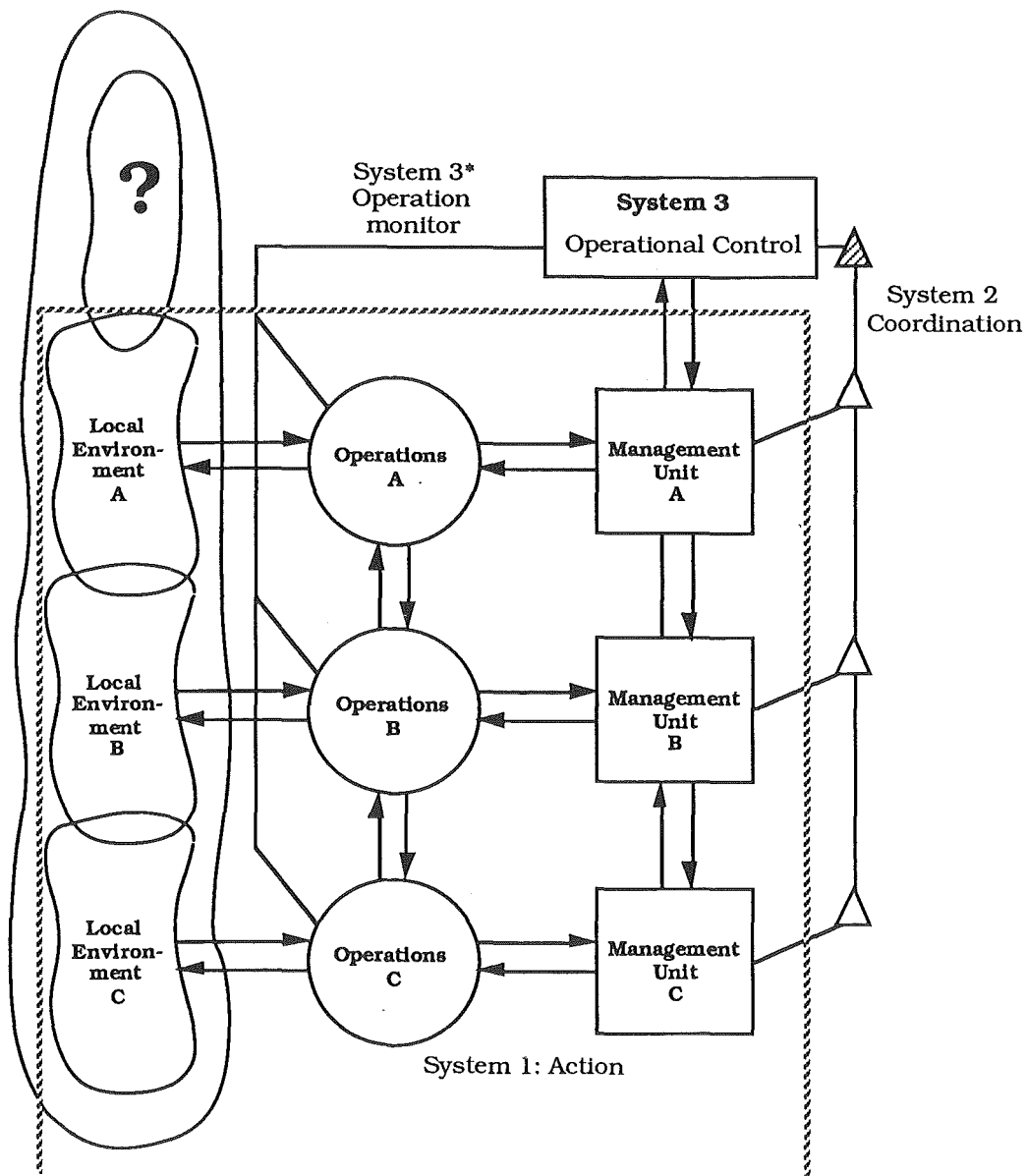


Figure 5 System 3

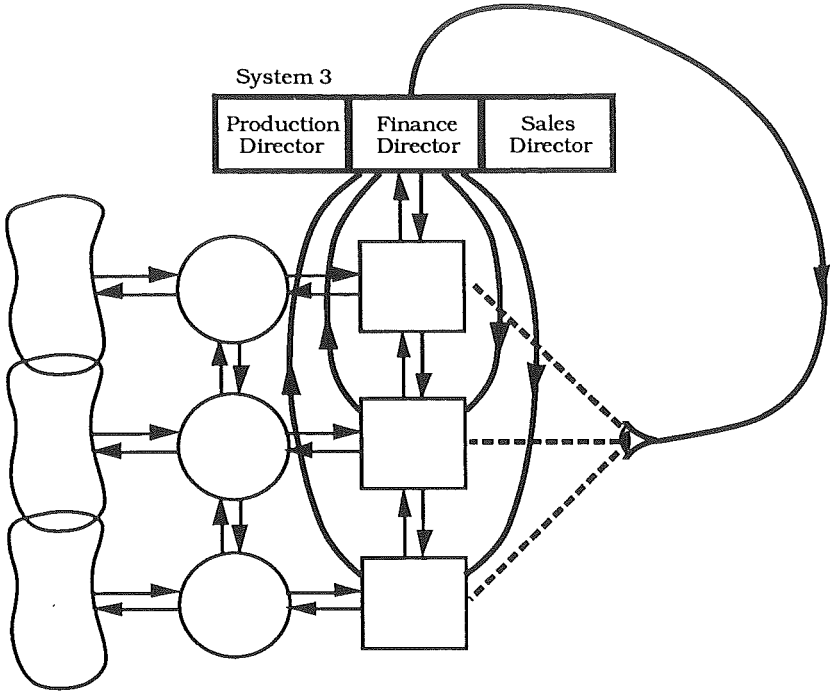


Figure 6a An Example of System 3 Acting for Benefit of System 1  
Copied From Beer (1979)

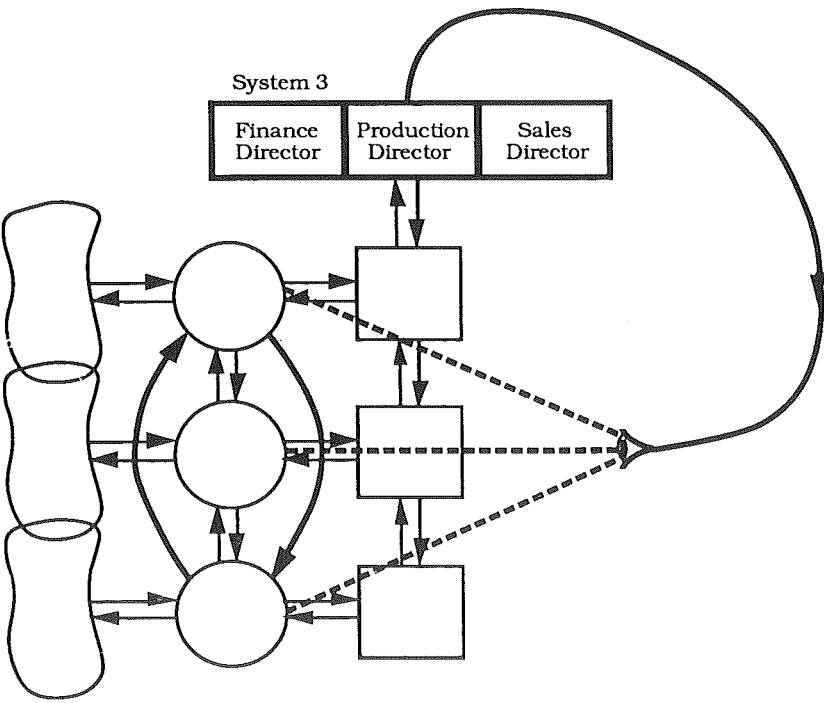


Figure 6b

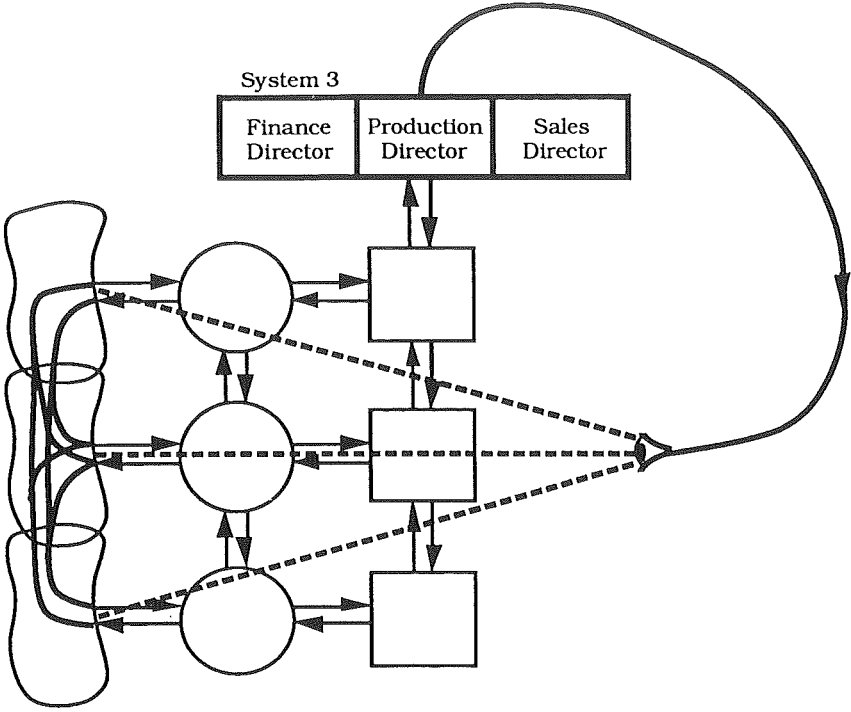


Figure 6c

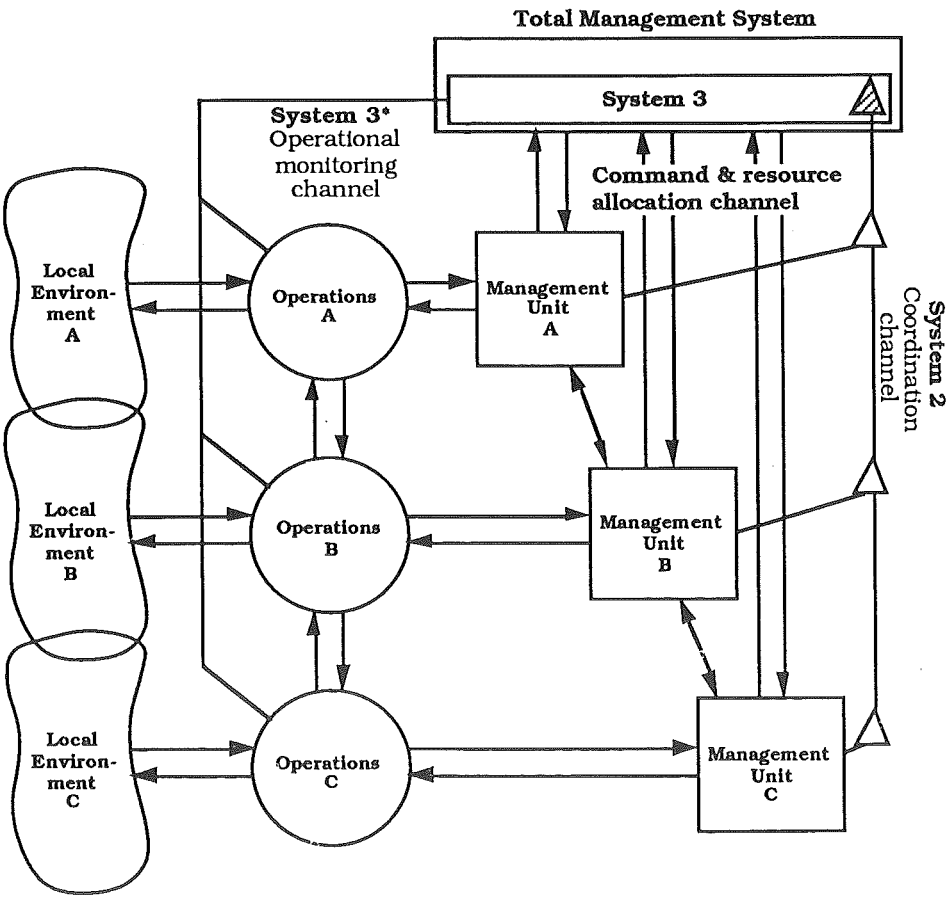


Figure 7 Three Channels of Communication Between System 3 and System 1

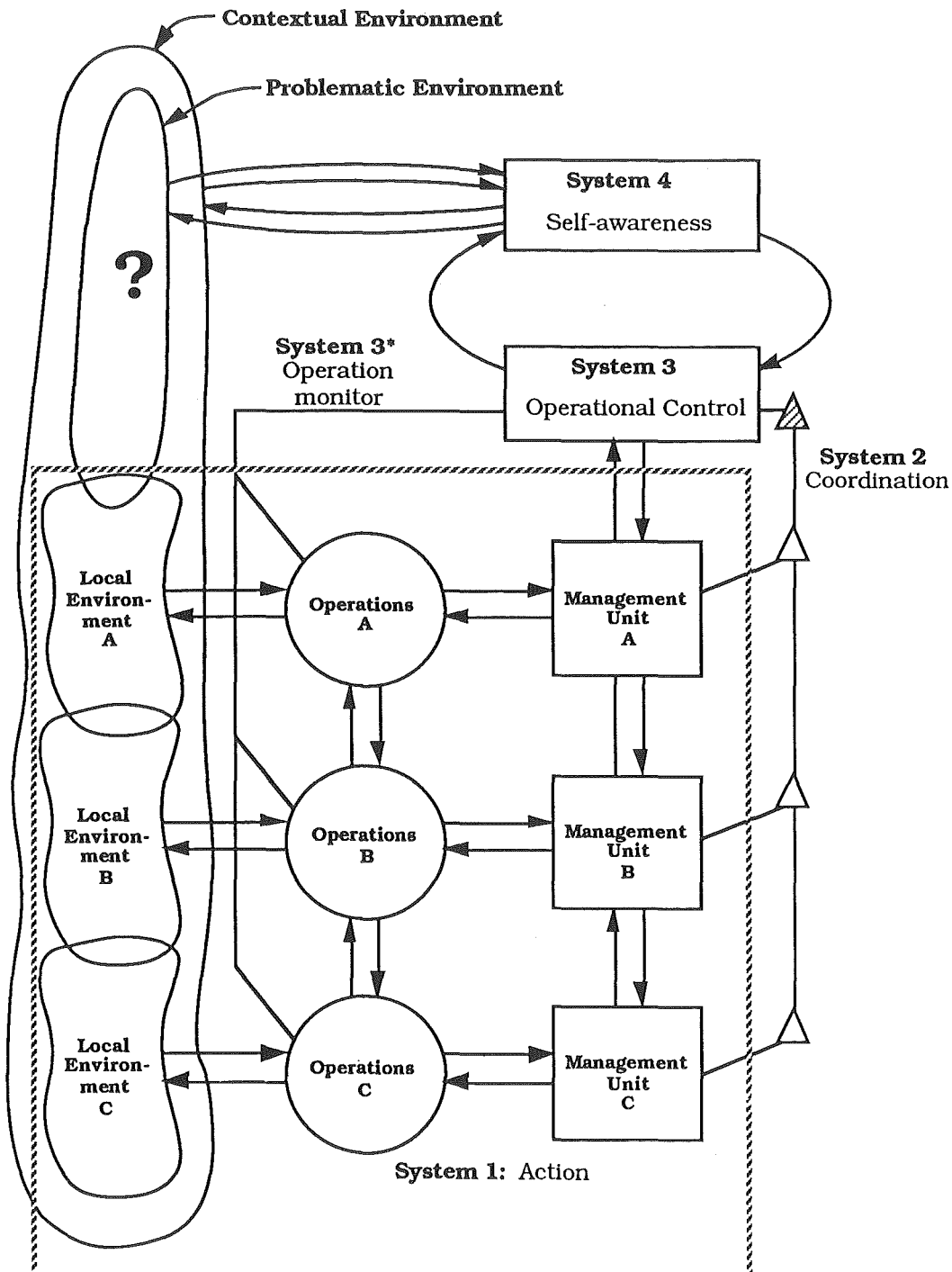


Figure 8 System 4

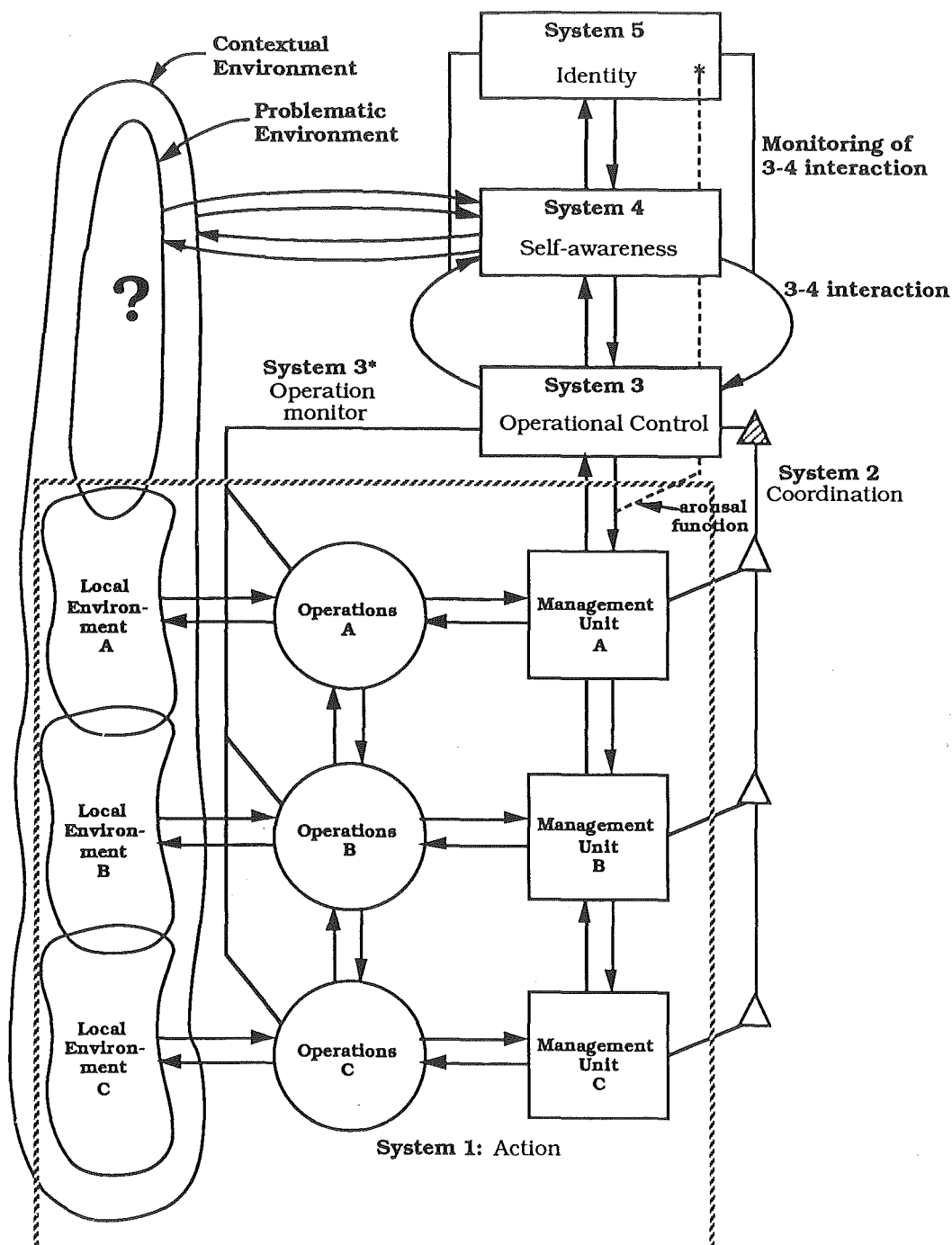


Figure 9 System 5



Figure 10 A Recursive Cartoon (From Punch)



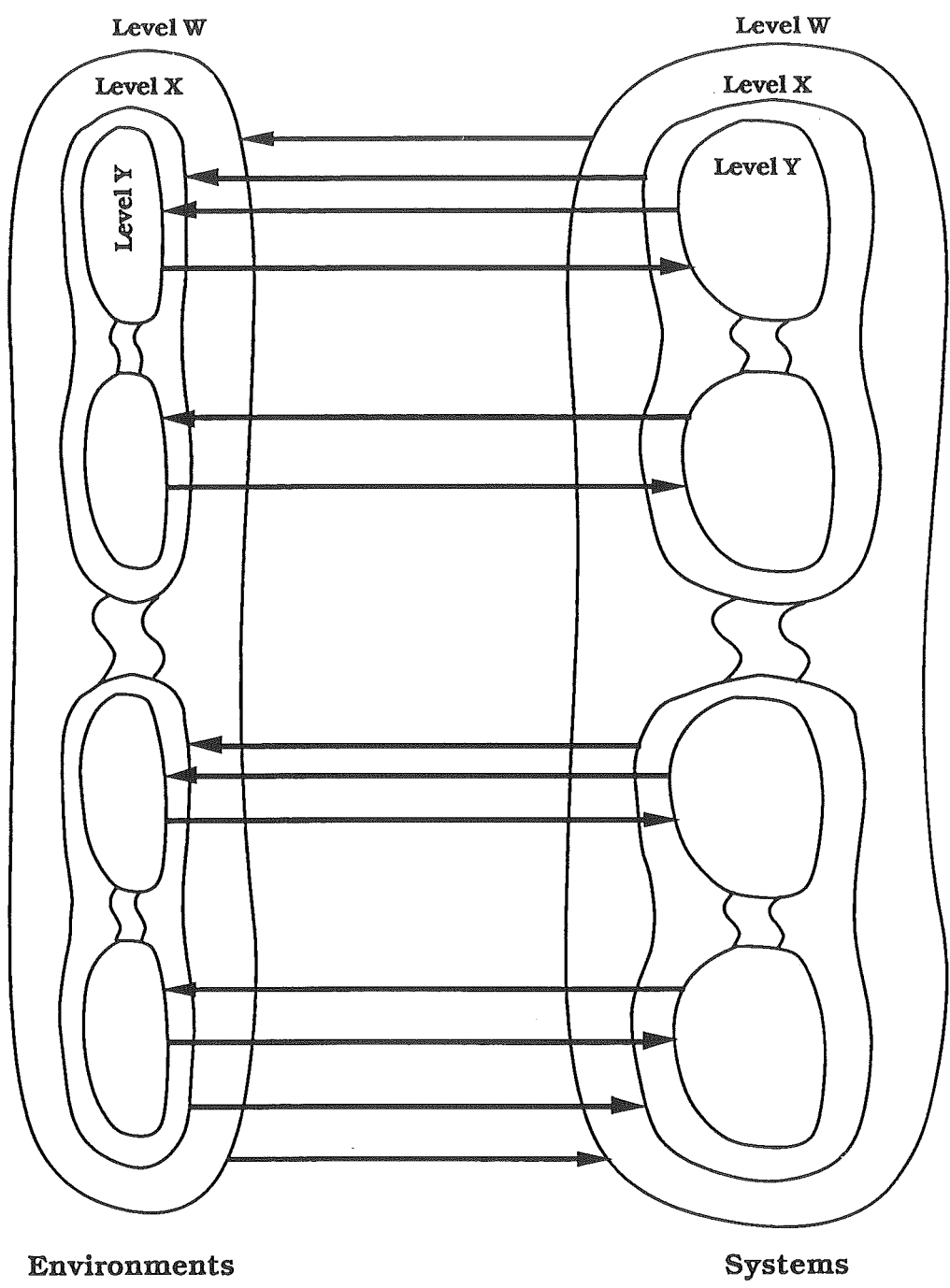


Figure 11 Levels of Systems and Environments

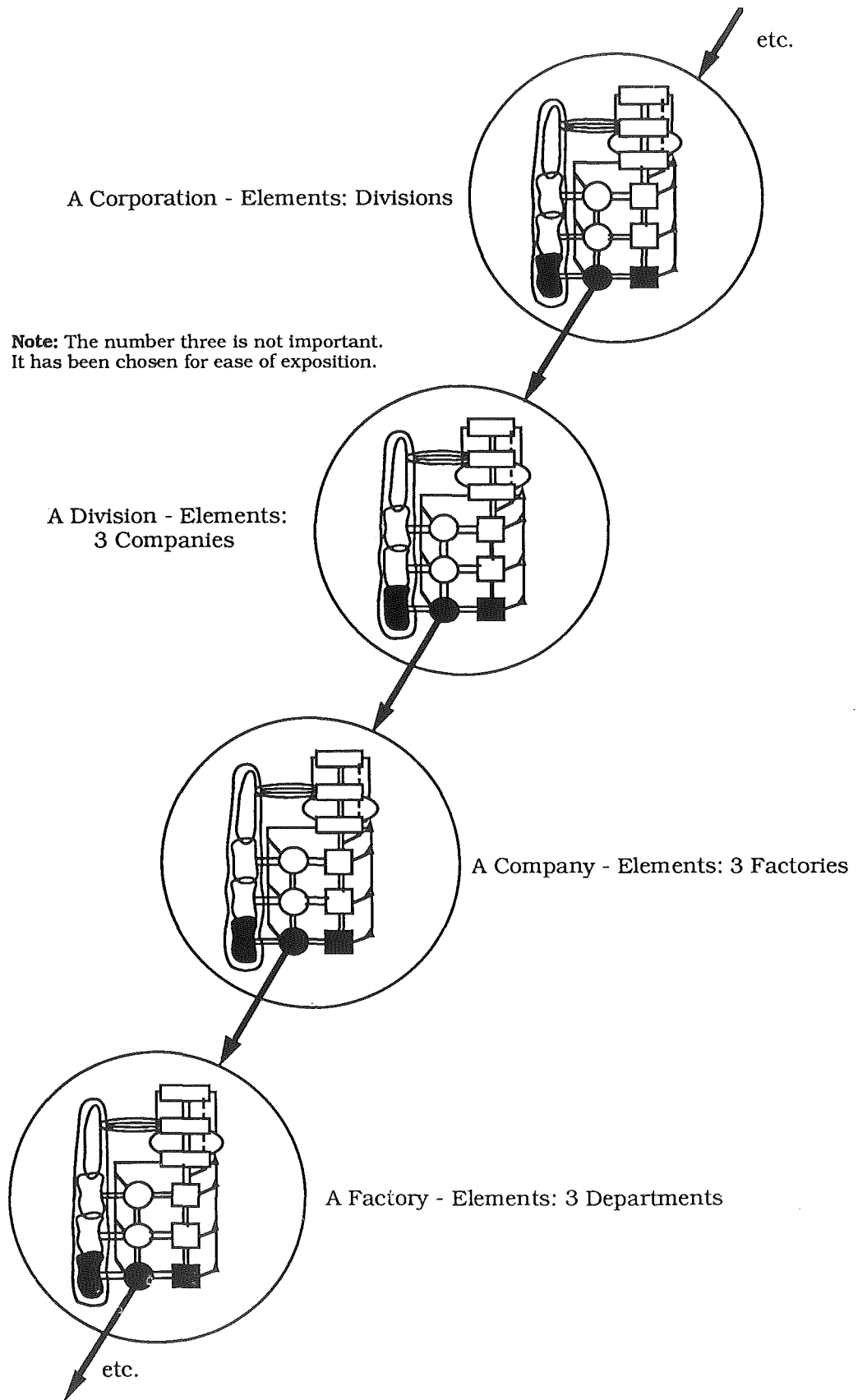


Figure 12 Levels of Recursion for a Corporation  
Copied from Beer (1979)

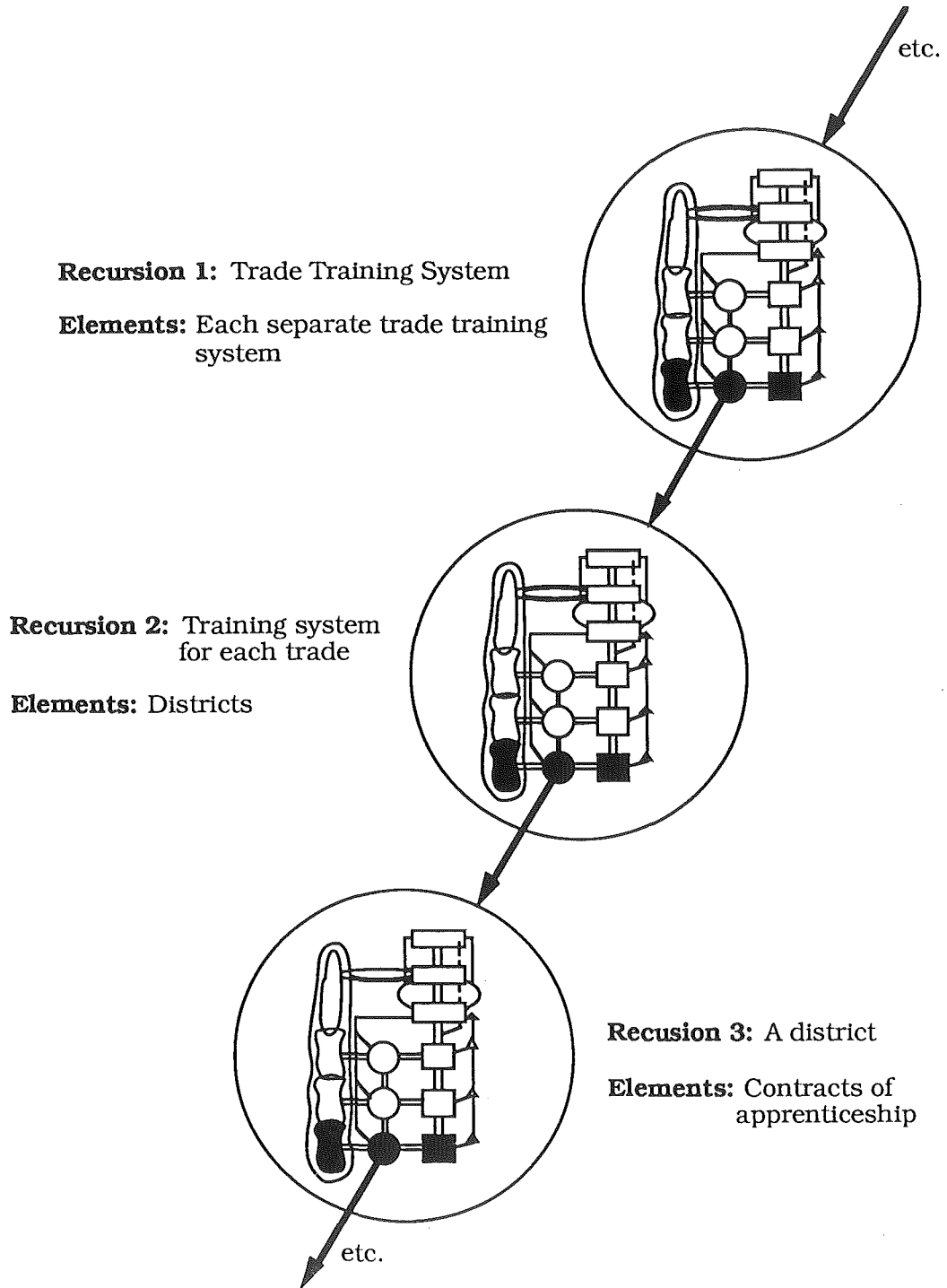


Figure 13 Levels of Recursion for Trade Training (N.Z.)

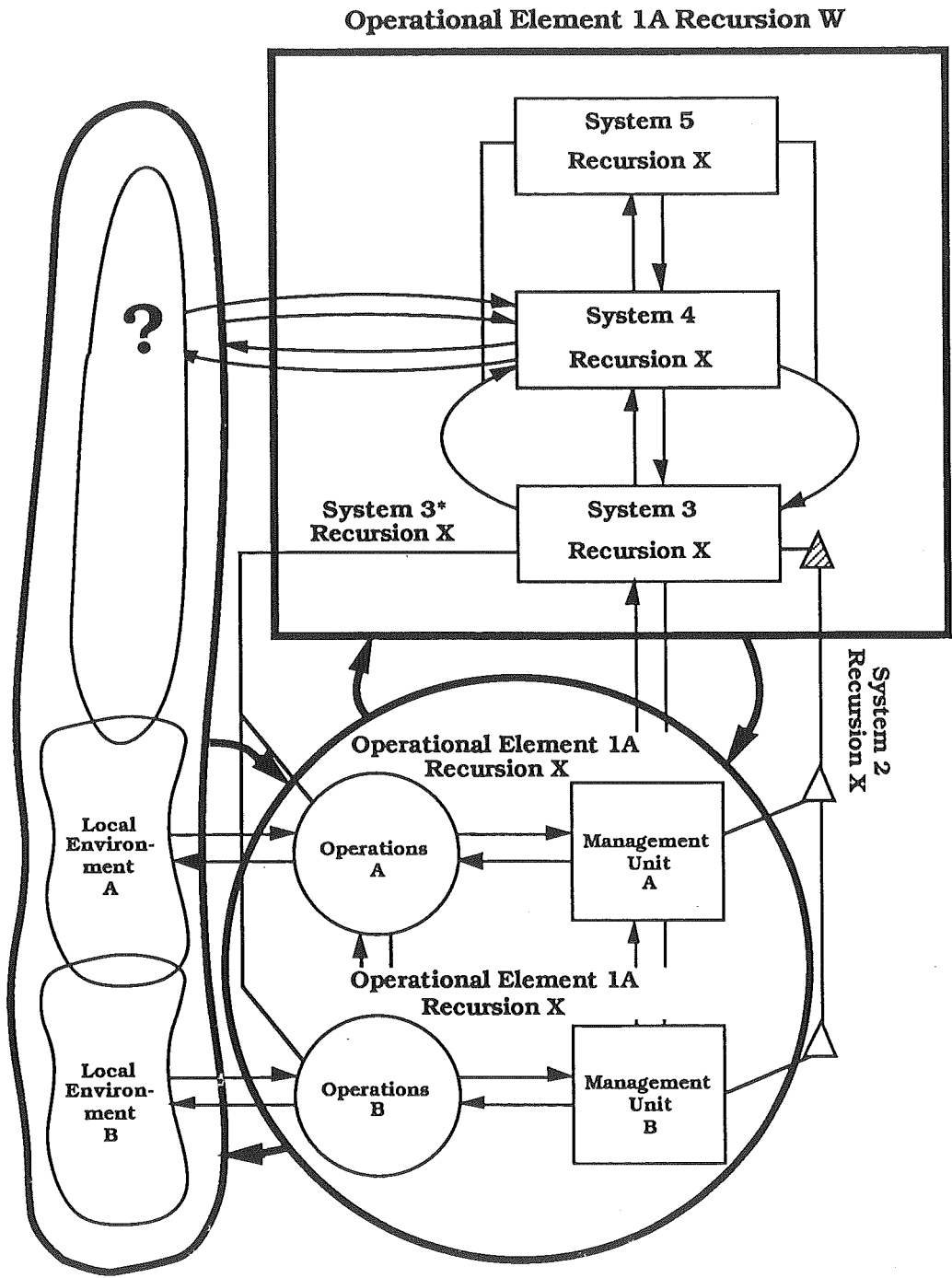


Figure 14 Linking Between Levels of Recursion

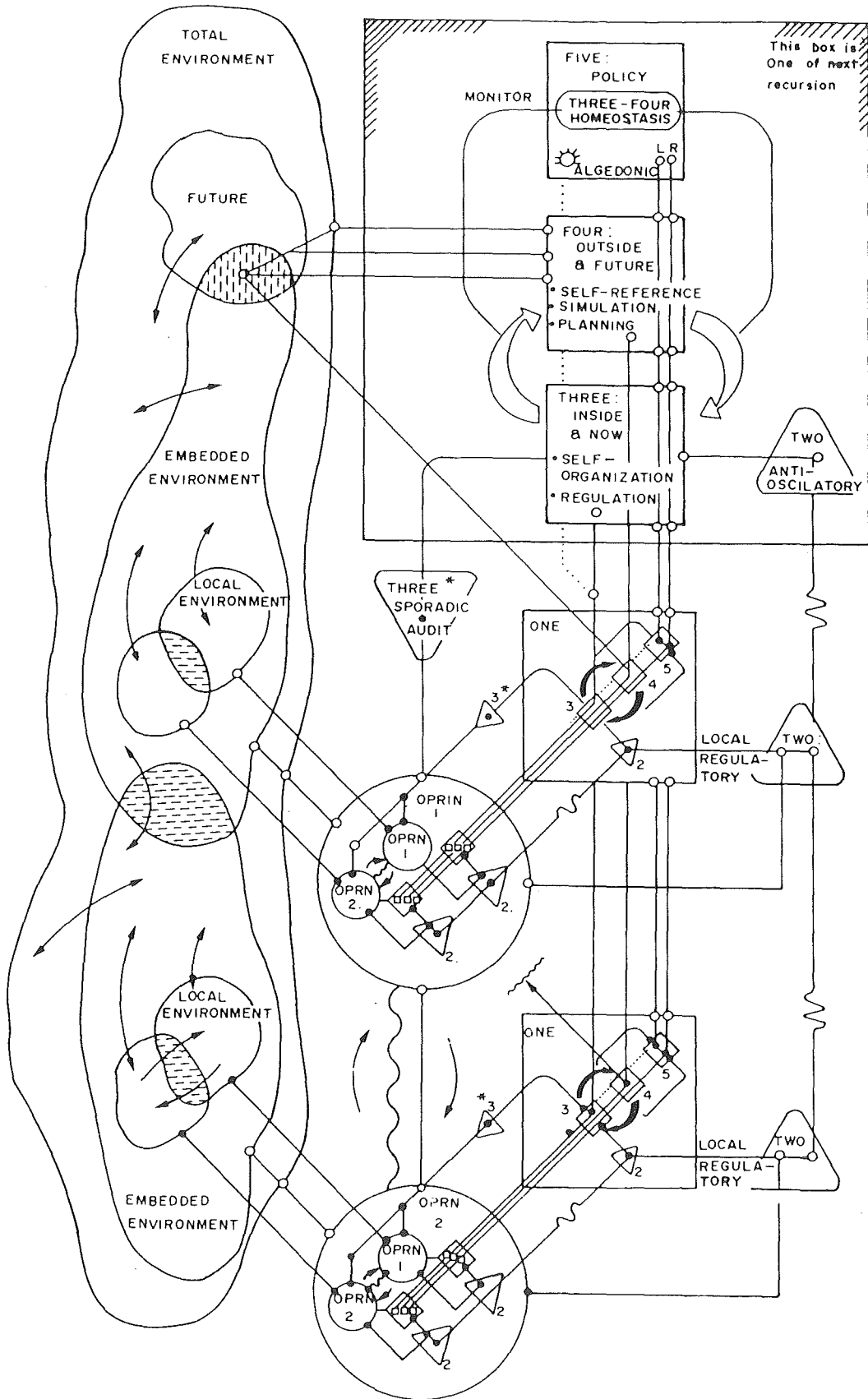


Figure 15 The Viable System Model  
Copied From Beer

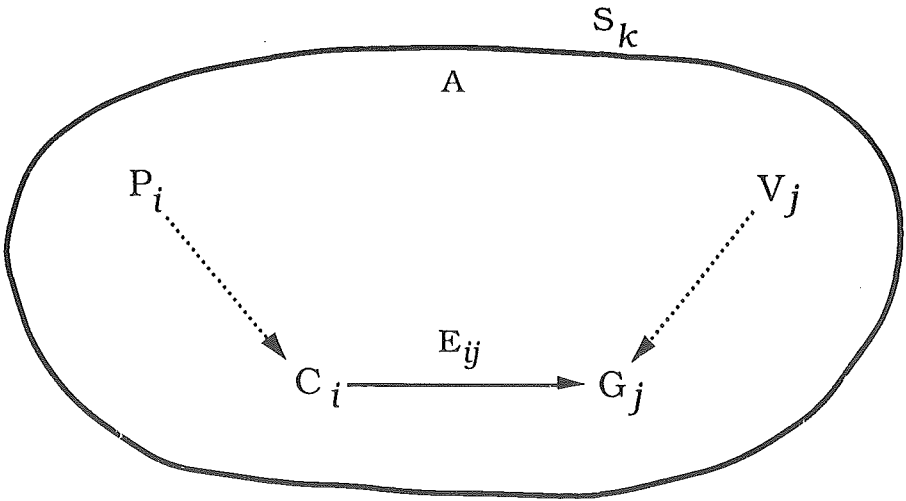
# APPENDIX B

## CHARACTERISTICS OF PEOPLE

In general people may be classified as purposeful systems, hence in a particular choice situation ( $S_k$ ) a person (A) may have a relative goal reference and relative action preference. Having chosen a goal to aim for and a course of action to execute in pursuit of the goal, she (A) needs to have the necessary practical knowledge, often referred to as skill, to execute the course of action. As a measure of skill we shall use the word efficiency, to denote the probability a person has of achieving a particular goal  $G_j$  in a particular duration of time by executing a particular course of action  $C_i$ ; efficiency will be represented by the symbol  $E_{ij}$ . That is, a person's efficiency  $E_{ij}$  in a particular situation  $S_k$  is a measure of her skill in the situation  $S_k$ .

We shall let  $P_i$  be the probability that a person (A) will choose course of action  $C_i$ , her relative action preference; and  $V_j$  be the probability that she will choose to pursue goal  $G_j$ , her relative goal preference, in a particular situation  $S_k$ .

We may indicate this diagrammatically as follows:



Assuming that a person's behaviour is stable in time, by observing her behaviour in a range of situations we could correlate classes of her behaviour with the situations to give measures of her  $P_i$ ,  $E_{ij}$ , and  $V_j$  and use these to anticipate how she would behave in similar situations in the future. That is, we could learn what goals she would seek, what actions she would choose to execute and how skilled she was. We shall refer to the set  $P_i$ ,  $E_{ij}$  and  $V_j$  as the person's functional properties. A person's capability in a particular situation is given by her set of  $E_{ij}$ 's and her character is given by her sets of  $P_i$  and  $V_j$ .

As has already been said, a person's goal preference is situation dependent. There are inbuilt priority indicators such as hunger and thirst, there are socially programmed indicators such as beliefs and feelings about one's value to a social group as interpreted from the behaviour of others, and there are self generated indicators such as beliefs and feelings about one's own aspirations and abilities.

Let us consider a person to be an integrated body-mind system, the mind being a sub-system that co-produces perceptions, beliefs, fears, feelings, intentions, etc, from sensation co-produced by the body and the system's environment. As the system's environment is comprised of non-living matter, living matter other than people, and people, in addition to producing sensation, it may produce structural damage to or structural restraint on the freedom of the body; it may interact with the body to upset its normal functioning; it may fail to supply food and water to sustain the normal functions of the body; or it may communicate meaning or otherwise influence the functioning of the mind. That is, it may do anatomical damage, it may restrain or constrain the freedom of anatomical movement of the body, it may upset or prevent the normal physiological processes, or it may have an influence psychologically.

We commonly say that we feel satisfied or we feel dissatisfied. In this use of the word *feel* we do not mean perceive from sensations produced by touching: rather we mean *a state of mind*. When a

person feels satisfied she is in a state of mind such that she would not summon up the energy necessary to change the situation she is in. When a person feels dissatisfied she is in a state of mind that would energize her to change the situation she is in, provided she has the other components of the necessary power.

One person may feel satisfied in a particular situation (i.e. with the structural and functional properties of the components of the situation including of herself) and another person may feel dissatisfied in that same situation. Whether or not a person is satisfied with a situation depends upon many factors; what is more a person may be satisfied with a situation at one moment of time and be dissatisfied with a similar situation at a later moment of time.

Feelings can relate to present or believed future anatomical, physiological and psychological states of the person concerned, to the present or believed future power of the person to achieve her own goals and the present or believed future power of a social group (to which she belongs) to achieve group goals. They can also be produced by uncertainty in believed future states or believed future powers.

Our interest in this topic arises because the relative priority a person ascribes to a goal (and to a course of action) appears to be related to the class of situation producing the dissatisfaction, the change in level of dissatisfaction she believes achievement of the goal would produce, and the power she believes she has to achieve the goal.

According to Maslow there is an hierarchy of needs. We need to feel anatomically and physiologically comfortable, and we need to feel that these comforts are not threatened. When those needs are satisfied we need to feel we belong to a social group that loves and empathises with us. When these needs are satisfied we need to feel that we are useful members of the social group and that our contribution is valued by other members of our social group. When those needs are satisfied we need to feel free to develop our



own personality, so that we are skilled in creative pursuits and so that we value the pursuit of perfection for its own sake.

Hence Maslow gives us an indication of the relative priorities we expect to find in people (i.e. the relative *extrinsic values* they have for goal states or states experienced).

A person may choose to execute a particular course of action because, for her goal, it is the most efficient available to her. On the other hand she may choose one less efficient for her goal but which she enjoys performing. Hence a person's relative preference for a course of action may depend upon the *instrumental value* she has for the course of action (which depends upon her beliefs about its efficiency for her goal) and upon its *intrinsic value* (i.e. upon the satisfaction she expects to derive from performing it).

### **On changes in a person's functional properties**

It is common experience that a person may extend the set of courses of action she can perform efficiently, become more efficient at courses of action already known, change her relative action preferences and her relative goal preferences in regularly experienced choice situations and adopt new relative preferences for goals and actions in new choice situations.

She may accomplish these changes with or without the assistance of one or more other people. Later we shall consider what a person needs to do to adapt unaided to new environments, but here we shall consider changes assisted by other people, which involves communicating messages.

Messages are sets of signs or symbols intended to convey meaning from the mind of the sender to the mind of the receiver.

We shall say that messages that change the receiver's relative preferences for courses of action in a particular choice situation convey *information*; messages that change her relative

preferences for goals (i.e. her intentions) in a particular choice situation convey *motivation*; and that those that increase her efficiency for a given course of action in a particular choice situation, increases her *knowledge* and conveys *instruction*.

If over a range of choice situations she knows variations of an appropriate course of action each with a given efficiency for one particular goal and if in any one choice situation she always chooses the most efficient variation we shall say she *understands* the course of action. Hence understanding is responsiveness to factors that affect efficiency. A message that increases understanding is said to convey *enlightenment*.

### **The power of a person**

The power of a person to attain or maintain satisfaction in a particular environment depends upon:

- a) her psychological properties, such as
  - i) her responsiveness to stimuli, that is her perceptiveness,
  - ii) the relevance and correctness of her memories,
  - iii) the correctness of her beliefs about the situation she is in and about the availability of potential future states,
  - iv) her relative preferences for goals she believes to be achievable,
  - v) the information she has upon which to base her relative preferences for available courses of action,
  - vi) her knowledge or understanding of the courses of action with potential to produce the intended state,
  - vii) her intelligence, that is her ability to increase, overtime, her knowledge or understanding of courses of action (by acting, observing and inferring),
  - viii) the strength and persistence of her will (i.e. of her intentions or feelings) for her chosen goal.
- b) her anatomical and physiological properties that co-produce her actions, and hence coproduce her outcomes
- c) the duration of time she has available in which to achieve her chosen goal,

- d) the availability of technical processes to co-produce the structural state associated with her chosen goal,
- e) the availability of tools and other technical instruments, and energy and other resources, to enable or to amplify a), b), or c) above (this could depend upon her having the permission or authority of the "owners", of the instruments and resources, to use them)
- f) the availability of social processes to co-produce her chosen goal state,
- g) the availability of social instruments (such as executive social systems) to enable or to amplify a), b) or c) above (this could depend upon her having the cooperation of people involved, including having their authority to command or lead them).

A versatile person is one that has the power to attain satisfaction in a range of choice situations.

In all situations in which a person lacks the power to achieve her intended goals, but especially in new situations including those brought about by having new intentions, a person may increase her power by:

- a) learning; that is by increasing, overtime,
  - i) her probability of choosing the most efficient course of action with potential for her goal in a particular class of environments; or
  - ii) the efficiency with which she executes her chosen courses of action. In other words, a person may increase her power in new classes of environments by increasing, over time, her knowledge or understanding of courses of action related to the pursuit of a relevant class of goals in the new classes of environments. It includes learning to inform, instruct and motivate other people.
- b) developing new technical or social instruments more powerful or more efficient than those already available with which to co-produce processes involved in changing or in maintaining states.

Developing may be defined as a process in which a new instrument is gradually evolved. It involves producing an hypothesis about a form of instrument that would increase the efficiency of a course of action, or the power of a person for a goal, producing the new form, testing it, checking the validity of the hypothesis, producing a further hypothesis, and so on until an instrument of the required power or efficiency is achieved.

When a person's beliefs are correct about the necessary and sufficient properties of elements of an instrument and about relationships between them, and when, given a specified set of functional properties for such an instrument, she can infer the relationships between and properties of its elements by an efficient course of action, we say she can design such instruments. Designing an instrument may be defined as a process in which a specification of the properties of and relationships between the elements of the instrument are derived by a proven inferential procedure.

c) planning what to do, how to do it, who should do it and what is needed to do it in advance of the time for action. Because technical and social processes for producing or for preventing a change have time delays between the initiating actions and the outcomes produced, and because there is often a penalty (for example, a higher level of dissatisfaction or a more prolonged state of dissatisfaction) for delays in initiating the processes, more power is often achieved by inferring and deciding, well in advance of the time for action, a) the goals that should be chosen for a given purpose; b) the courses of action that should be executed in pursuit of the chosen goals, c) who should act and when they should act; d) the instruments that will be required and when they will be required; e) the other resources that will be required and when they will be required; f) the agreement of people concerned (for example, those likely to be affected by the actions or the outcomes of the project) to the goal being pursued, to the proposed courses of action being executed, to the resources being used, etc. Like the instrument designing process, the action planning process is comprised of proven inferential processes

based upon correct information and correct beliefs. When the goals efficient for the purpose or the courses of action efficient for a goal cannot be inferred because proven processes are not available a learning situation arises.

### **A person as a viable purposeful system**

A person needs to be able to perform many courses of action efficiently and to be able to arrange them to perform many functions in different environments. She makes decisions continuously as to which of her knowledge or understanding is appropriate in each different situation. She chooses her goals and plans, executes and regulates her hour by hour and day by day activities in such a manner that statistically stationary recurring environmental disturbances do not prevent her achieving her goals. However, in the longer term, unique and statistically non-stationary classes of environmental changes are likely to be encountered. To cope with some of these requires new powers (e.g. new knowledge or understanding or the assistance of new instruments). Learning, and developing new instruments, are only accomplished overtime, so if her longer term plans are to be brought to fruition she must plan to form correct beliefs about future environmental states sufficiently far in advance to allow her time to gain the new powers she will require.

Of course, she must balance the time and energy she allocates to gain new powers for activities to meet her future needs and desires against the time and energy she allocates to meet her current needs and desires.

Her needs are those for her to remain viable (including those required to keep her alive and those to maintain both her freedom to act purposefully and her character). Her desires include all other states she may hanker after.

In summary she must manage the day-to-day performance of her existing functions to cope efficiently and effectively with the short term changes in environmental states or actions, so that in the

short term she remains viable and has the satisfaction of achieving many of her other desires. In addition she must anticipate longer term changes in environmental states or actions, then learn new functions or modify her knowledge or understanding of existing functions, or develop new instruments so that she also remains viable and accomplishes many of her desires for the foreseeable future.

### **Exercises**

1. Explain what you understand by the functional properties of a person.

How may another person influence each of those functional properties?

2. In terms of functional properties explain what you understand by the culture of a social group.

3. Outline the factors upon which the power of a person in a particular choice situation depends.

4. How may a person increase her power relative to her environment in new environmental situations?

5. What activities must a person manage if she is to remain a viable system, where viability includes maintaining her body, as a living organ, maintaining her freedom to act purposefully and maintaining her character.

## APPENDIX C

### GST CONTAINER

The GST is a curtain sided container built by New Zealand Railways for domestic freight.

It has been designed to maximise load space and give the most efficient loading of commonly used New Zealand pallets and loads. For example; chep pallets, ABC pallets and 2.4m x 1.2m boards.

Specific details are as follows.

#### **Load Capacity**

The container has a floor area of 2.5m wide by 6.1m long which is greater than international standard dimensions. This allows either 12 chep pallets or 10 ABC pallets to be fitted into the container with a 100mm allowance for loading.

Johnson Wax Ltd who have trialed the prototype container (called GTX34) have achieved a 20% load increase over standard containers.

#### **Compatibility**

The container's locating points are to standard dimensions, enabling it to fit on wagons and trucks. The container can be lifted by all handling equipment including swing lift trucks.

#### **Damage Reduction**

Because chep, ABC pallets and other common loads give a near perfect fit within the container, no load movement is possible when in transit, reducing product damage and eliminating the need for dunnaging or other forms of load restraint.

For those loads that do not fit exactly within the container dimensions, the production model has been designed with tie down points within the end walls, the roof and along the full length of the base sides to ensure loads can be fully secured.

### **Ease of use**

Experience with the prototype has shown that standard ratchet curtain-sider mechanisms are difficult to use on containers and prone to damage.

The production model of the container will be fitted with easy to use, over centre latches at the ends to tension the curtains.

### **Security**

Special attention has been paid to security. Latches at the curtain ends will be lockable as will all tensioning buckles by the use of a wire rope.

Design work is currently being put into lightweight aluminium mesh frames which can be pulled down from within the roof and fit behind the curtain to give vandal protection. If this design proves successful, these may be fitted on containers carrying high value goods.

### **Insulated Versions**

If a demand is shown to exist, a number of these containers may be fitted with an insulated roof and insulated curtain sides to protect loads from both excessive heat in summer and excessive cold in winter.

### **Production**

Finance has been approved for seventy of these containers. One prototype has been in service for 9 months and a second, pre-production prototype will be constructed in July. Full scale production of the remaining containers will begin in August/September.